
NetworkX Reference

Release 1.10

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September 30, 2015

CONTENTS

1	Overview	1
1.1	Who uses NetworkX?	1
1.2	Goals	1
1.3	The Python programming language	1
1.4	Free software	2
1.5	History	2
2	Introduction	3
2.1	NetworkX Basics	3
2.2	Nodes and Edges	4
3	Graph types	9
3.1	Which graph class should I use?	9
3.2	Basic graph types	9
4	Algorithms	25
4.1	Approximation	25
4.2	Assortativity	34
4.3	Bipartite	34
4.4	Blockmodeling	61
4.5	Boundary	61
4.6	Centrality	63
4.7	Chordal	64
4.8	Clique	67
4.9	Clustering	70
4.10	Coloring	74
4.11	Communities	74
4.12	Components	75
4.13	Connectivity	91
4.14	Cores	109
4.15	Cycles	112
4.16	Directed Acyclic Graphs	115
4.17	Distance Measures	119
4.18	Distance-Regular Graphs	121
4.19	Dominance	123
4.20	Dominating Sets	124
4.21	Eulerian	125
4.22	Flows	126
4.23	Graphical degree sequence	127
4.24	Hierarchy	130
4.25	Hybrid	131

4.26	Isolates	132
4.27	Isomorphism	133
4.28	Link Analysis	135
4.29	Link Prediction	142
4.30	Matching	148
4.31	Minors	149
4.32	Maximal independent set	153
4.33	Minimum Spanning Tree	153
4.34	Operators	155
4.35	Rich Club	164
4.36	Shortest Paths	165
4.37	Simple Paths	183
4.38	Swap	185
4.39	Traversal	186
4.40	Tree	194
4.41	Triads	199
4.42	Vitality	200
5	Functions	201
5.1	Graph	201
5.2	Nodes	202
5.3	Edges	204
5.4	Attributes	205
5.5	Freezing graph structure	207
6	Graph generators	209
6.1	Atlas	209
6.2	Classic	209
6.3	Expanders	214
6.4	Small	215
6.5	Random Graphs	219
6.6	Degree Sequence	227
6.7	Random Clustered	233
6.8	Directed	234
6.9	Geometric	237
6.10	Line Graph	240
6.11	Ego Graph	241
6.12	Stochastic	242
6.13	Intersection	243
6.14	Social Networks	244
6.15	Community	245
6.16	Non Isomorphic Trees	249
7	Linear algebra	251
7.1	Graph Matrix	251
7.2	Laplacian Matrix	252
7.3	Spectrum	255
7.4	Algebraic Connectivity	256
7.5	Attribute Matrices	258
8	Converting to and from other data formats	263
8.1	To NetworkX Graph	263
8.2	Dictionaries	264
8.3	Lists	264
8.4	Numpy	266

8.5	Scipy	270
8.6	Pandas	272
9	Reading and writing graphs	275
9.1	Adjacency List	275
9.2	Multiline Adjacency List	278
9.3	Edge List	282
9.4	GEXF	288
9.5	GML	290
9.6	Pickle	294
9.7	GraphML	295
9.8	JSON	298
9.9	LED A	298
9.10	YAML	299
9.11	SparseGraph6	300
9.12	Pajek	306
9.13	GIS Shapefile	307
10	Drawing	309
10.1	Matplotlib	309
10.2	Graphviz AGraph (dot)	317
10.3	Graphviz with pydot	319
10.4	Graph Layout	321
11	Exceptions	325
11.1	Exceptions	325
12	Utilities	327
12.1	Helper Functions	327
12.2	Data Structures and Algorithms	328
12.3	Random Sequence Generators	328
12.4	Decorators	330
12.5	Cuthill-McKee Ordering	331
12.6	Context Managers	333
13	License	335
14	Citing	337
15	Credits	339
15.1	Contributions	339
15.2	Support	341
16	Glossary	343
	Python Module Index	345
	Index	349

OVERVIEW

NetworkX is a Python language software package for the creation, manipulation, and study of the structure, dynamics, and function of complex networks.

With NetworkX you can load and store networks in standard and nonstandard data formats, generate many types of random and classic networks, analyze network structure, build network models, design new network algorithms, draw networks, and much more.

1.1 Who uses NetworkX?

The potential audience for NetworkX includes mathematicians, physicists, biologists, computer scientists, and social scientists. Good reviews of the state-of-the-art in the science of complex networks are presented in Albert and Barabási [BA02], Newman [Newman03], and Dorogovtsev and Mendes [DM03]. See also the classic texts [Bollobas01], [Diestel97] and [West01] for graph theoretic results and terminology. For basic graph algorithms, we recommend the texts of Sedgewick, e.g. [Sedgewick01] and [Sedgewick02] and the survey of Brandes and Erlebach [BE05].

1.2 Goals

NetworkX is intended to provide

- tools for the study of the structure and dynamics of social, biological, and infrastructure networks,
- a standard programming interface and graph implementation that is suitable for many applications,
- a rapid development environment for collaborative, multidisciplinary projects,
- an interface to existing numerical algorithms and code written in C, C++, and FORTRAN,
- the ability to painlessly slurp in large nonstandard data sets.

1.3 The Python programming language

Python is a powerful programming language that allows simple and flexible representations of networks, and clear and concise expressions of network algorithms (and other algorithms too). Python has a vibrant and growing ecosystem of packages that NetworkX uses to provide more features such as numerical linear algebra and drawing. In addition Python is also an excellent “glue” language for putting together pieces of software from other languages which allows reuse of legacy code and engineering of high-performance algorithms [Langtangen04].

Equally important, Python is free, well-supported, and a joy to use.

In order to make the most out of NetworkX you will want to know how to write basic programs in Python. Among the many guides to Python, we recommend the documentation at <http://www.python.org> and the text by Alex Martelli [Martelli03].

1.4 Free software

NetworkX is free software; you can redistribute it and/or modify it under the terms of the [BSD License](#). We welcome contributions from the community. Information on NetworkX development is found at the NetworkX Developer Zone at Github <https://github.com/networkx/networkx>

1.5 History

NetworkX was born in May 2002. The original version was designed and written by Aric Hagberg, Dan Schult, and Pieter Swart in 2002 and 2003. The first public release was in April 2005.

Many people have contributed to the success of NetworkX. Some of the contributors are listed in the [credits](#).

1.5.1 What Next

- [A Brief Tour](#)
- [Installing](#)
- [Reference](#)
- [Examples](#)

INTRODUCTION

The structure of NetworkX can be seen by the organization of its source code. The package provides classes for graph objects, generators to create standard graphs, IO routines for reading in existing datasets, algorithms to analyse the resulting networks and some basic drawing tools.

Most of the NetworkX API is provided by functions which take a graph object as an argument. Methods of the graph object are limited to basic manipulation and reporting. This provides modularity of code and documentation. It also makes it easier for newcomers to learn about the package in stages. The source code for each module is meant to be easy to read and reading this Python code is actually a good way to learn more about network algorithms, but we have put a lot of effort into making the documentation sufficient and friendly. If you have suggestions or questions please contact us by joining the [NetworkX Google group](#).

Classes are named using CamelCase (capital letters at the start of each word). functions, methods and variable names are lower_case_underscore (lowercase with an underscore representing a space between words).

2.1 NetworkX Basics

After starting Python, import the networkx module with (the recommended way)

```
>>> import networkx as nx
```

To save repetition, in the documentation we assume that NetworkX has been imported this way.

If importing networkx fails, it means that Python cannot find the installed module. Check your installation and your PYTHONPATH.

The following basic graph types are provided as Python classes:

Graph This class implements an undirected graph. It ignores multiple edges between two nodes. It does allow self-loop edges between a node and itself.

DiGraph Directed graphs, that is, graphs with directed edges. Operations common to directed graphs, (a subclass of Graph).

MultiGraph A flexible graph class that allows multiple undirected edges between pairs of nodes. The additional flexibility leads to some degradation in performance, though usually not significant.

MultiDiGraph A directed version of a MultiGraph.

Empty graph-like objects are created with

```
>>> G=nx.Graph()
>>> G=nx.DiGraph()
>>> G=nx.MultiGraph()
>>> G=nx.MultiDiGraph()
```

All graph classes allow any *hashable* object as a node. Hashable objects include strings, tuples, integers, and more. Arbitrary edge attributes such as weights and labels can be associated with an edge.

The graph internal data structures are based on an adjacency list representation and implemented using Python *dictionary* datastructures. The graph adjacency structure is implemented as a Python dictionary of dictionaries; the outer dictionary is keyed by nodes to values that are themselves dictionaries keyed by neighboring node to the edge attributes associated with that edge. This “dict-of-dicts” structure allows fast addition, deletion, and lookup of nodes and neighbors in large graphs. The underlying datastructure is accessed directly by methods (the programming interface “API”) in the class definitions. All functions, on the other hand, manipulate graph-like objects solely via those API methods and not by acting directly on the datastructure. This design allows for possible replacement of the ‘dicts-of-dicts’-based datastructure with an alternative datastructure that implements the same methods.

2.1.1 Graphs

The first choice to be made when using NetworkX is what type of graph object to use. A graph (network) is a collection of nodes together with a collection of edges that are pairs of nodes. Attributes are often associated with nodes and/or edges. NetworkX graph objects come in different flavors depending on two main properties of the network:

- **Directed:** Are the edges **directed**? Does the order of the edge pairs (u,v) matter? A directed graph is specified by the “Di” prefix in the class name, e.g. `DiGraph()`. We make this distinction because many classical graph properties are defined differently for directed graphs.
- **Multi-edges:** Are multiple edges allowed between each pair of nodes? As you might imagine, multiple edges requires a different data structure, though tricky users could design edge data objects to support this functionality. We provide a standard data structure and interface for this type of graph using the prefix “Multi”, e.g. `MultiGraph()`.

The basic graph classes are named: `Graph`, `DiGraph`, `MultiGraph`, and `MultiDiGraph`

2.2 Nodes and Edges

The next choice you have to make when specifying a graph is what kinds of nodes and edges to use.

If the topology of the network is all you care about then using integers or strings as the nodes makes sense and you need not worry about edge data. If you have a data structure already in place to describe nodes you can simply use that structure as your nodes provided it is *hashable*. If it is not hashable you can use a unique identifier to represent the node and assign the data as a *node attribute*.

Edges often have data associated with them. Arbitrary data can associated with edges as an *edge attribute*. If the data is numeric and the intent is to represent a *weighted* graph then use the ‘weight’ keyword for the attribute. Some of the graph algorithms, such as Dijkstra’s shortest path algorithm, use this attribute name to get the weight for each edge.

Other attributes can be assigned to an edge by using keyword/value pairs when adding edges. You can use any keyword except ‘weight’ to name your attribute and can then easily query the edge data by that attribute keyword.

Once you’ve decided how to encode the nodes and edges, and whether you have an undirected/directed graph with or without multiedges you are ready to build your network.

2.2.1 Graph Creation

NetworkX graph objects can be created in one of three ways:

- Graph generators – standard algorithms to create network topologies.
- Importing data from pre-existing (usually file) sources.

- Adding edges and nodes explicitly.

Explicit addition and removal of nodes/edges is the easiest to describe. Each graph object supplies methods to manipulate the graph. For example,

```
>>> import networkx as nx
>>> G=nx.Graph()
>>> G.add_edge(1,2) # default edge data=1
>>> G.add_edge(2,3,weight=0.9) # specify edge data
```

Edge attributes can be anything:

```
>>> import math
>>> G.add_edge('y','x',function=math.cos)
>>> G.add_node(math.cos) # any hashable can be a node
```

You can add many edges at one time:

```
>>> elist=[('a','b',5.0),('b','c',3.0),('a','c',1.0),('c','d',7.3)]
>>> G.add_weighted_edges_from(elist)
```

See the [/tutorial/index](#) for more examples.

Some basic graph operations such as union and intersection are described in the [Operators module](#) documentation.

Graph generators such as `binomial_graph` and `powerlaw_graph` are provided in the [Graph generators](#) subpackage.

For importing network data from formats such as GML, GraphML, edge list text files see the [Reading and writing graphs](#) subpackage.

2.2.2 Graph Reporting

Class methods are used for the basic reporting functions `neighbors`, `edges` and `degree`. Reporting of lists is often needed only to iterate through that list so we supply iterator versions of many property reporting methods. For example `edges()` and `nodes()` have corresponding methods `edges_iter()` and `nodes_iter()`. Using these methods when you can will save memory and often time as well.

The basic graph relationship of an edge can be obtained in two basic ways. One can look for neighbors of a node or one can look for edges incident to a node. We jokingly refer to people who focus on nodes/neighbors as node-centric and people who focus on edges as edge-centric. The designers of NetworkX tend to be node-centric and view edges as a relationship between nodes. You can see this by our avoidance of notation like $G[u,v]$ in favor of $G[u][v]$. Most data structures for sparse graphs are essentially adjacency lists and so fit this perspective. In the end, of course, it doesn't really matter which way you examine the graph. `G.edges()` removes duplicate representations of each edge while `G.neighbors(n)` or `G[n]` is slightly faster but doesn't remove duplicates.

Any properties that are more complicated than edges, neighbors and degree are provided by functions. For example `nx.triangles(G,n)` gives the number of triangles which include node `n` as a vertex. These functions are grouped in the code and documentation under the term *algorithms*.

2.2.3 Algorithms

A number of graph algorithms are provided with NetworkX. These include shortest path, and breadth first search (see [traversal](#)), clustering and isomorphism algorithms and others. There are many that we have not developed yet too. If you implement a graph algorithm that might be useful for others please let us know through the [NetworkX Google group](#) or the Github [Developer Zone](#).

As an example here is code to use Dijkstra's algorithm to find the shortest weighted path:

```
>>> G=nx.Graph()
>>> e=[('a','b',0.3), ('b','c',0.9), ('a','c',0.5), ('c','d',1.2)]
>>> G.add_weighted_edges_from(e)
>>> print(nx.dijkstra_path(G, 'a', 'd'))
['a', 'c', 'd']
```

2.2.4 Drawing

While NetworkX is not designed as a network layout tool, we provide a simple interface to drawing packages and some simple layout algorithms. We interface to the excellent Graphviz layout tools like dot and neato with the (suggested) pygraphviz package or the pydot interface. Drawing can be done using external programs or the Matplotlib Python package. Interactive GUI interfaces are possible though not provided. The drawing tools are provided in the module *drawing*.

The basic drawing functions essentially place the nodes on a scatterplot using the positions in a dictionary or computed with a layout function. The edges are then lines between those dots.

```
>>> G=nx.cubical_graph()
>>> nx.draw(G) # default spring_layout
>>> nx.draw(G, pos=nx.spectral_layout(G), nodecolor='r', edge_color='b')
```

See the examples for more ideas.

2.2.5 Data Structure

NetworkX uses a “dictionary of dictionaries of dictionaries” as the basic network data structure. This allows fast lookup with reasonable storage for large sparse networks. The keys are nodes so `G[u]` returns an adjacency dictionary keyed by neighbor to the edge attribute dictionary. The expression `G[u][v]` returns the edge attribute dictionary itself. A dictionary of lists would have also been possible, but not allowed fast edge detection nor convenient storage of edge data.

Advantages of dict-of-dicts-of-dicts data structure:

- Find edges and remove edges with two dictionary look-ups.
- Prefer to “lists” because of fast lookup with sparse storage.
- Prefer to “sets” since data can be attached to edge.
- `G[u][v]` returns the edge attribute dictionary.
- `n in G` tests if node `n` is in graph `G`.
- `for n in G:` iterates through the graph.
- `for nbr in G[n]:` iterates through neighbors.

As an example, here is a representation of an undirected graph with the edges ('A','B'), ('B','C')

```
>>> G=nx.Graph()
>>> G.add_edge('A', 'B')
>>> G.add_edge('B', 'C')
>>> print(G.adj)
{'A': {'B': {}}, 'C': {'B': {}}, 'B': {'A': {}, 'C': {}}}
```

The data structure gets morphed slightly for each base graph class. For `DiGraph` two dict-of-dicts-of-dicts structures are provided, one for successors and one for predecessors. For `MultiGraph`/`MultiDiGraph` we use a dict-of-dicts-of-

dicts-of-dicts¹ where the third dictionary is keyed by an edge key identifier to the fourth dictionary which contains the edge attributes for that edge between the two nodes.

Graphs use a dictionary of attributes for each edge. We use a dict-of-dicts-of-dicts data structure with the inner dictionary storing “name-value” relationships for that edge.

```
>>> G=nx.Graph()
>>> G.add_edge(1,2,color='red',weight=0.84,size=300)
>>> print(G[1][2]['size'])
300
```

¹ “It’s dictionaries all the way down.”

GRAPH TYPES

NetworkX provides data structures and methods for storing graphs.

All NetworkX graph classes allow (hashable) Python objects as nodes. and any Python object can be assigned as an edge attribute.

The choice of graph class depends on the structure of the graph you want to represent.

3.1 Which graph class should I use?

Graph Type	NetworkX Class
Undirected Simple	Graph
Directed Simple	DiGraph
With Self-loops	Graph, DiGraph
With Parallel edges	MultiGraph, MultiDiGraph

3.2 Basic graph types

3.2.1 Graph – Undirected graphs with self loops

Overview

Graph (*data=None, **attr*)

Base class for undirected graphs.

A Graph stores nodes and edges with optional data, or attributes.

Graphs hold undirected edges. Self loops are allowed but multiple (parallel) edges are not.

Nodes can be arbitrary (hashable) Python objects with optional key/value attributes.

Edges are represented as links between nodes with optional key/value attributes.

Parameters

- **data** (*input graph*) – Data to initialize graph. If data=None (default) an empty graph is created. The data can be an edge list, or any NetworkX graph object. If the corresponding optional Python packages are installed the data can also be a NumPy matrix or 2d ndarray, a SciPy sparse matrix, or a PyGraphviz graph.
- **attr** (*keyword arguments, optional (default= no attributes)*) – Attributes to add to graph as key=value pairs.

See also:

DiGraph(), *MultiGraph()*, *MultiDiGraph()*

Examples

Create an empty graph structure (a “null graph”) with no nodes and no edges.

```
>>> G = nx.Graph()
```

G can be grown in several ways.

Nodes:

Add one node at a time:

```
>>> G.add_node(1)
```

Add the nodes from any container (a list, dict, set or even the lines from a file or the nodes from another graph).

```
>>> G.add_nodes_from([2, 3])
>>> G.add_nodes_from(range(100, 110))
>>> H=nx.Graph()
>>> H.add_path([0, 1, 2, 3, 4, 5, 6, 7, 8, 9])
>>> G.add_nodes_from(H)
```

In addition to strings and integers any hashable Python object (except None) can represent a node, e.g. a customized node object, or even another Graph.

```
>>> G.add_node(H)
```

Edges:

G can also be grown by adding edges.

Add one edge,

```
>>> G.add_edge(1, 2)
```

a list of edges,

```
>>> G.add_edges_from([(1, 2), (1, 3)])
```

or a collection of edges,

```
>>> G.add_edges_from(H.edges())
```

If some edges connect nodes not yet in the graph, the nodes are added automatically. There are no errors when adding nodes or edges that already exist.

Attributes:

Each graph, node, and edge can hold key/value attribute pairs in an associated attribute dictionary (the keys must be hashable). By default these are empty, but can be added or changed using `add_edge`, `add_node` or direct manipulation of the attribute dictionaries named `graph`, `node` and `edge` respectively.

```
>>> G = nx.Graph(day="Friday")
>>> G.graph
{'day': 'Friday'}
```

Add node attributes using `add_node()`, `add_nodes_from()` or `G.node`


```

>>> G.add_node(1, time='5pm')
>>> G.add_nodes_from([3], time='2pm')
>>> G.node[1]
{'time': '5pm'}
>>> G.node[1]['room'] = 714
>>> del G.node[1]['room'] # remove attribute
>>> G.nodes(data=True)
[(1, {'time': '5pm'}), (3, {'time': '2pm'})]

```

Warning: adding a node to G.node does not add it to the graph.

Add edge attributes using add_edge(), add_edges_from(), subscript notation, or G.edge.

```

>>> G.add_edge(1, 2, weight=4.7)
>>> G.add_edges_from([(3,4), (4,5)], color='red')
>>> G.add_edges_from([(1,2,{'color':'blue'}), (2,3,{'weight':8})])
>>> G[1][2]['weight'] = 4.7
>>> G.edge[1][2]['weight'] = 4

```

Shortcuts:

Many common graph features allow python syntax to speed reporting.

```

>>> 1 in G      # check if node in graph
True
>>> [n for n in G if n<3] # iterate through nodes
[1, 2]
>>> len(G)      # number of nodes in graph
5

```

The fastest way to traverse all edges of a graph is via adjacency_iter(), but the edges() method is often more convenient.

```

>>> for n,nbrsdict in G.adjacency_iter():
...     for nbr,eattr in nbrsdict.items():
...         if 'weight' in eattr:
...             (n,nbr,eattr['weight'])
(1, 2, 4)
(2, 1, 4)
(2, 3, 8)
(3, 2, 8)
>>> G.edges(data='weight')
[(1, 2, 4), (2, 3, 8), (3, 4, None), (4, 5, None)]

```

Reporting:

Simple graph information is obtained using methods. Iterator versions of many reporting methods exist for efficiency. Methods exist for reporting nodes(), edges(), neighbors() and degree() as well as the number of nodes and edges.

For details on these and other miscellaneous methods, see below.

Subclasses (Advanced):

The Graph class uses a dict-of-dict-of-dict data structure. The outer dict (node_dict) holds adjacency lists keyed by node. The next dict (adlist) represents the adjacency list and holds edge data keyed by neighbor. The inner dict (edge_attr) represents the edge data and holds edge attribute values keyed by attribute names.

Each of these three dicts can be replaced by a user defined dict-like object. In general, the dict-like features should be maintained but extra features can be added. To replace one of the dicts create a new graph

class by changing the class(!) variable holding the factory for that dict-like structure. The variable names are `node_dict_factory`, `adjlist_dict_factory` and `edge_attr_dict_factory`.

node_dict_factory [function, (default: dict)] Factory function to be used to create the outer-most dict in the data structure that holds adjacency lists keyed by node. It should require no arguments and return a dict-like object.

adjlist_dict_factory [function, (default: dict)] Factory function to be used to create the adjacency list dict which holds edge data keyed by neighbor. It should require no arguments and return a dict-like object

edge_attr_dict_factory [function, (default: dict)] Factory function to be used to create the edge attribute dict which holds attribute values keyed by attribute name. It should require no arguments and return a dict-like object.

Examples

Create a graph object that tracks the order nodes are added.

```
>>> from collections import OrderedDict
>>> class OrderedNodeGraph(nx.Graph):
...     node_dict_factory=OrderedDict
>>> G=OrderedNodeGraph()
>>> G.add_nodes_from( (2,1) )
>>> G.nodes()
[2, 1]
>>> G.add_edges_from( ((2,2), (2,1), (1,1)) )
>>> G.edges()
[(2, 1), (2, 2), (1, 1)]
```

Create a graph object that tracks the order nodes are added and for each node track the order that neighbors are added.

```
>>> class OrderedGraph(nx.Graph):
...     node_dict_factory = OrderedDict
...     adjlist_dict_factory = OrderedDict
>>> G = OrderedGraph()
>>> G.add_nodes_from( (2,1) )
>>> G.nodes()
[2, 1]
>>> G.add_edges_from( ((2,2), (2,1), (1,1)) )
>>> G.edges()
[(2, 2), (2, 1), (1, 1)]
```

Create a low memory graph class that effectively disallows edge attributes by using a single attribute dict for all edges. This reduces the memory used, but you lose edge attributes.

```
>>> class ThinGraph(nx.Graph):
...     all_edge_dict = {'weight': 1}
...     def single_edge_dict(self):
...         return self.all_edge_dict
...     edge_attr_dict_factory = single_edge_dict
>>> G = ThinGraph()
>>> G.add_edge(2,1)
>>> G.edges(data=True)
[(1, 2, {'weight': 1})]
>>> G.add_edge(2,2)
>>> G[2][1] is G[2][2]
True
```

Adding and removing nodes and edges

Iterating over nodes and edges

Information about graph structure

Making copies and subgraphs

3.2.2 DiGraph - Directed graphs with self loops

Overview

DiGraph (*data=None, **attr*)

Base class for directed graphs.

A DiGraph stores nodes and edges with optional data, or attributes.

DiGraphs hold directed edges. Self loops are allowed but multiple (parallel) edges are not.

Nodes can be arbitrary (hashable) Python objects with optional key/value attributes.

Edges are represented as links between nodes with optional key/value attributes.

Parameters

- **data** (*input graph*) – Data to initialize graph. If data=None (default) an empty graph is created. The data can be an edge list, or any NetworkX graph object. If the corresponding optional Python packages are installed the data can also be a NumPy matrix or 2d ndarray, a SciPy sparse matrix, or a PyGraphviz graph.
- **attr** (*keyword arguments, optional (default= no attributes)*) – Attributes to add to graph as key=value pairs.

See also:

`Graph()`, `MultiGraph()`, `MultiDiGraph()`

Examples

Create an empty graph structure (a “null graph”) with no nodes and no edges.

```
>>> G = nx.DiGraph()
```

G can be grown in several ways.

Nodes:

Add one node at a time:

```
>>> G.add_node(1)
```

Add the nodes from any container (a list, dict, set or even the lines from a file or the nodes from another graph).

```
>>> G.add_nodes_from([2,3])
>>> G.add_nodes_from(range(100,110))
>>> H=nx.Graph()
>>> H.add_path([0,1,2,3,4,5,6,7,8,9])
>>> G.add_nodes_from(H)
```

In addition to strings and integers any hashable Python object (except None) can represent a node, e.g. a customized node object, or even another Graph.

```
>>> G.add_node(H)
```

Edges:

G can also be grown by adding edges.

Add one edge,

```
>>> G.add_edge(1, 2)
```

a list of edges,

```
>>> G.add_edges_from([(1,2), (1,3)])
```

or a collection of edges,

```
>>> G.add_edges_from(H.edges())
```

If some edges connect nodes not yet in the graph, the nodes are added automatically. There are no errors when adding nodes or edges that already exist.

Attributes:

Each graph, node, and edge can hold key/value attribute pairs in an associated attribute dictionary (the keys must be hashable). By default these are empty, but can be added or changed using `add_edge`, `add_node` or direct manipulation of the attribute dictionaries named `graph`, `node` and `edge` respectively.

```
>>> G = nx.DiGraph(day="Friday")
>>> G.graph
{'day': 'Friday'}
```

Add node attributes using `add_node()`, `add_nodes_from()` or `G.node`

```
>>> G.add_node(1, time='5pm')
>>> G.add_nodes_from([3], time='2pm')
>>> G.node[1]
{'time': '5pm'}
>>> G.node[1]['room'] = 714
>>> del G.node[1]['room'] # remove attribute
>>> G.nodes(data=True)
[(1, {'time': '5pm'}), (3, {'time': '2pm'})]
```

Warning: adding a node to `G.node` does not add it to the graph.

Add edge attributes using `add_edge()`, `add_edges_from()`, subscript notation, or `G.edge`.

```
>>> G.add_edge(1, 2, weight=4.7)
>>> G.add_edges_from([(3,4), (4,5)], color='red')
>>> G.add_edges_from([(1,2,{'color':'blue'}), (2,3,{'weight':8})])
```

```
>>> G[1][2]['weight'] = 4.7
>>> G.edge[1][2]['weight'] = 4
```

Shortcuts:

Many common graph features allow python syntax to speed reporting.

```
>>> 1 in G      # check if node in graph
True
>>> [n for n in G if n<3]  # iterate through nodes
[1, 2]
>>> len(G)      # number of nodes in graph
5
```

The fastest way to traverse all edges of a graph is via `adjacency_iter()`, but the `edges()` method is often more convenient.

```
>>> for n,nbrsdict in G.adjacency_iter():
...     for nbr,eattr in nbrsdict.items():
...         if 'weight' in eattr:
...             (n,nbr,eattr['weight'])
(1, 2, 4)
(2, 3, 8)
>>> G.edges(data='weight')
[(1, 2, 4), (2, 3, 8), (3, 4, None), (4, 5, None)]
```

Reporting:

Simple graph information is obtained using methods. Iterator versions of many reporting methods exist for efficiency. Methods exist for reporting `nodes()`, `edges()`, `neighbors()` and `degree()` as well as the number of nodes and edges.

For details on these and other miscellaneous methods, see below.

Subclasses (Advanced):

The Graph class uses a dict-of-dict-of-dict data structure. The outer dict (`node_dict`) holds adjacency lists keyed by node. The next dict (`adjlist`) represents the adjacency list and holds edge data keyed by neighbor. The inner dict (`edge_attr`) represents the edge data and holds edge attribute values keyed by attribute names.

Each of these three dicts can be replaced by a user defined dict-like object. In general, the dict-like features should be maintained but extra features can be added. To replace one of the dicts create a new graph class by changing the class(!) variable holding the factory for that dict-like structure. The variable names are `node_dict_factory`, `adjlist_dict_factory` and `edge_attr_dict_factory`.

node_dict_factory [function, optional (default: dict)] Factory function to be used to create the outer-most dict in the data structure that holds adjacency lists keyed by node. It should require no arguments and return a dict-like object.

adjlist_dict_factory [function, optional (default: dict)] Factory function to be used to create the adjacency list dict which holds edge data keyed by neighbor. It should require no arguments and return a dict-like object

edge_attr_dict_factory [function, optional (default: dict)] Factory function to be used to create the edge attribute dict which holds attribute values keyed by attribute name. It should require no arguments and return a dict-like object.

Examples

Create a graph object that tracks the order nodes are added.

```
>>> from collections import OrderedDict
>>> class OrderedNodeGraph(nx.Graph):
...     node_dict_factory=OrderedDict
>>> G=OrderedNodeGraph()
>>> G.add_nodes_from( (2,1) )
>>> G.nodes()
[2, 1]
>>> G.add_edges_from( ((2,2), (2,1), (1,1)) )
>>> G.edges()
[(2, 1), (2, 2), (1, 1)]
```

Create a graph object that tracks the order nodes are added and for each node track the order that neighbors are added.

```
>>> class OrderedGraph(nx.Graph):
...     node_dict_factory = OrderedDict
...     adjlist_dict_factory = OrderedDict
>>> G = OrderedGraph()
>>> G.add_nodes_from( (2,1) )
>>> G.nodes()
[2, 1]
>>> G.add_edges_from( ((2,2), (2,1), (1,1)) )
>>> G.edges()
[(2, 2), (2, 1), (1, 1)]
```

Create a low memory graph class that effectively disallows edge attributes by using a single attribute dict for all edges. This reduces the memory used, but you lose edge attributes.

```
>>> class ThinGraph(nx.Graph):
...     all_edge_dict = {'weight': 1}
...     def single_edge_dict(self):
...         return self.all_edge_dict
...     edge_attr_dict_factory = single_edge_dict
>>> G = ThinGraph()
>>> G.add_edge(2,1)
>>> G.edges(data= True)
[(1, 2, {'weight': 1})]
>>> G.add_edge(2,2)
>>> G[2][1] is G[2][2]
True
```

Adding and removing nodes and edges

Iterating over nodes and edges

Information about graph structure

Making copies and subgraphs

3.2.3 MultiGraph - Undirected graphs with self loops and parallel edges

Overview

MultiGraph (*data=None, **attr*)

An undirected graph class that can store multiedges.

Multiedges are multiple edges between two nodes. Each edge can hold optional data or attributes.

A MultiGraph holds undirected edges. Self loops are allowed.

Nodes can be arbitrary (hashable) Python objects with optional key/value attributes.

Edges are represented as links between nodes with optional key/value attributes.

Parameters

- **data** (*input graph*) – Data to initialize graph. If data=None (default) an empty graph is created. The data can be an edge list, or any NetworkX graph object. If the corresponding optional Python packages are installed the data can also be a NumPy matrix or 2d ndarray, a SciPy sparse matrix, or a PyGraphviz graph.
- **attr** (*keyword arguments, optional (default= no attributes)*) – Attributes to add to graph as key=value pairs.

See also:

`Graph()`, `DiGraph()`, `MultiDiGraph()`

Examples

Create an empty graph structure (a “null graph”) with no nodes and no edges.

```
>>> G = nx.MultiGraph()
```

G can be grown in several ways.

Nodes:

Add one node at a time:

```
>>> G.add_node(1)
```

Add the nodes from any container (a list, dict, set or even the lines from a file or the nodes from another graph).

```
>>> G.add_nodes_from([2,3])
>>> G.add_nodes_from(range(100,110))
>>> H=nx.Graph()
>>> H.add_path([0,1,2,3,4,5,6,7,8,9])
>>> G.add_nodes_from(H)
```

In addition to strings and integers any hashable Python object (except None) can represent a node, e.g. a customized node object, or even another Graph.

```
>>> G.add_node(H)
```

Edges:

G can also be grown by adding edges.

Add one edge,

```
>>> G.add_edge(1, 2)
```

a list of edges,

```
>>> G.add_edges_from([(1,2), (1,3)])
```

or a collection of edges,

```
>>> G.add_edges_from(H.edges())
```

If some edges connect nodes not yet in the graph, the nodes are added automatically. If an edge already exists, an additional edge is created and stored using a key to identify the edge. By default the key is the lowest unused integer.

```
>>> G.add_edges_from([(4,5,dict(route=282)), (4,5,dict(route=37))])
>>> G[4]
{3: {0: {}}, 5: {0: {}, 1: {'route': 282}, 2: {'route': 37}}}
```

Attributes:

Each graph, node, and edge can hold key/value attribute pairs in an associated attribute dictionary (the keys must be hashable). By default these are empty, but can be added or changed using `add_edge`, `add_node` or direct manipulation of the attribute dictionaries named `graph`, `node` and `edge` respectively.

```
>>> G = nx.MultiGraph(day="Friday")
>>> G.graph
{'day': 'Friday'}
```

Add node attributes using `add_node()`, `add_nodes_from()` or `G.node`

```
>>> G.add_node(1, time='5pm')
>>> G.add_nodes_from([3], time='2pm')
>>> G.node[1]
{'time': '5pm'}
>>> G.node[1]['room'] = 714
>>> del G.node[1]['room'] # remove attribute
>>> G.nodes(data=True)
[(1, {'time': '5pm'}), (3, {'time': '2pm'})]
```

Warning: adding a node to `G.node` does not add it to the graph.

Add edge attributes using `add_edge()`, `add_edges_from()`, subscript notation, or `G.edge`.

```
>>> G.add_edge(1, 2, weight=4.7)
>>> G.add_edges_from([(3,4), (4,5)], color='red')
>>> G.add_edges_from([(1,2,{'color':'blue'}), (2,3,{'weight':8})])
>>> G[1][2][0]['weight'] = 4.7
>>> G.edge[1][2][0]['weight'] = 4
```

Shortcuts:

Many common graph features allow python syntax to speed reporting.

```
>>> 1 in G      # check if node in graph
True
>>> [n for n in G if n<3]  # iterate through nodes
```



```
[1, 2]
>>> len(G)  # number of nodes in graph
5
>>> G[1]  # adjacency dict keyed by neighbor to edge attributes
...      # Note: you should not change this dict manually!
{2: {0: {'weight': 4}, 1: {'color': 'blue'}}}
```

The fastest way to traverse all edges of a graph is via `adjacency_iter()`, but the `edges()` method is often more convenient.

```
>>> for n,nbrsdict in G.adjacency_iter():
...     for nbr,keydict in nbrsdict.items():
...         for key,eattr in keydict.items():
...             if 'weight' in eattr:
...                 (n,nbr,key,eattr['weight'])
(1, 2, 0, 4)
(2, 1, 0, 4)
(2, 3, 0, 8)
(3, 2, 0, 8)
>>> G.edges(data='weight', keys=True)
[(1, 2, 0, 4), (1, 2, 1, None), (2, 3, 0, 8), (3, 4, 0, None), (4, 5, 0, None)]
```

Reporting:

Simple graph information is obtained using methods. Iterator versions of many reporting methods exist for efficiency. Methods exist for reporting `nodes()`, `edges()`, `neighbors()` and `degree()` as well as the number of nodes and edges.

For details on these and other miscellaneous methods, see below.

Subclasses (Advanced):

The `MultiGraph` class uses a dict-of-dict-of-dict-of-dict data structure. The outer dict (`node_dict`) holds adjacency lists keyed by node. The next dict (`adjlist`) represents the adjacency list and holds `edge_key` dicts keyed by neighbor. The `edge_key` dict holds each `edge_attr` dict keyed by edge key. The inner dict (`edge_attr`) represents the edge data and holds edge attribute values keyed by attribute names.

Each of these four dicts in the dict-of-dict-of-dict-of-dict structure can be replaced by a user defined dict-like object. In general, the dict-like features should be maintained but extra features can be added. To replace one of the dicts create a new graph class by changing the `class(!)` variable holding the factory for that dict-like structure. The variable names are `node_dict_factory`, `adjlist_dict_factory`, `edge_key_dict_factory` and `edge_attr_dict_factory`.

node_dict_factory [function, (default: dict)] Factory function to be used to create the outer-most dict in the data structure that holds adjacency lists keyed by node. It should require no arguments and return a dict-like object.

adjlist_dict_factory [function, (default: dict)] Factory function to be used to create the adjacency list dict which holds multiedge key dicts keyed by neighbor. It should require no arguments and return a dict-like object.

edge_key_dict_factory [function, (default: dict)] Factory function to be used to create the edge key dict which holds edge data keyed by edge key. It should require no arguments and return a dict-like object.

edge_attr_dict_factory [function, (default: dict)] Factory function to be used to create the edge attribute dict which holds attribute values keyed by attribute name. It should require no arguments and return a dict-like object.

Examples

Create a multigraph object that tracks the order nodes are added.

```
>>> from collections import OrderedDict
>>> class OrderedGraph(nx.MultiGraph):
...     node_dict_factory = OrderedDict
>>> G = OrderedGraph()
>>> G.add_nodes_from( (2,1) )
>>> G.nodes()
[2, 1]
>>> G.add_edges_from( ((2,2), (2,1), (2,1), (1,1)) )
>>> G.edges()
[(2, 1), (2, 1), (2, 2), (1, 1)]
```

Create a multigraph object that tracks the order nodes are added and for each node track the order that neighbors are added and for each neighbor tracks the order that multiedges are added.

```
>>> class OrderedGraph(nx.MultiGraph):
...     node_dict_factory = OrderedDict
...     adjlist_dict_factory = OrderedDict
...     edge_key_dict_factory = OrderedDict
>>> G = OrderedGraph()
>>> G.add_nodes_from( (2,1) )
>>> G.nodes()
[2, 1]
>>> G.add_edges_from( ((2,2), (2,1,2,{ 'weight':0.1}), (2,1,1,{ 'weight':0.2}), (1,1)) )
>>> G.edges(keys=True)
[(2, 2, 0), (2, 1, 2), (2, 1, 1), (1, 1, 0)]
```

Adding and removing nodes and edges

Iterating over nodes and edges

Information about graph structure

Making copies and subgraphs

3.2.4 MultiDiGraph - Directed graphs with self loops and parallel edges

Overview

MultiDiGraph (*data=None, **attr*)

A directed graph class that can store multiedges.

Multiedges are multiple edges between two nodes. Each edge can hold optional data or attributes.

A MultiDiGraph holds directed edges. Self loops are allowed.

Nodes can be arbitrary (hashable) Python objects with optional key/value attributes.

Edges are represented as links between nodes with optional key/value attributes.

Parameters

- **data** (*input graph*) – Data to initialize graph. If data=None (default) an empty graph is created. The data can be an edge list, or any NetworkX graph object. If the corresponding optional Python packages are installed the data can also be a NumPy matrix or 2d ndarray, a SciPy sparse matrix, or a PyGraphviz graph.
- **attr** (*keyword arguments, optional (default= no attributes)*) – Attributes to add to graph as key=value pairs.

See also:

`Graph()`, `DiGraph()`, `MultiGraph()`

Examples

Create an empty graph structure (a “null graph”) with no nodes and no edges.

```
>>> G = nx.MultiDiGraph()
```

G can be grown in several ways.

Nodes:

Add one node at a time:

```
>>> G.add_node(1)
```

Add the nodes from any container (a list, dict, set or even the lines from a file or the nodes from another graph).

```
>>> G.add_nodes_from([2,3])
>>> G.add_nodes_from(range(100,110))
>>> H=nx.Graph()
>>> H.add_path([0,1,2,3,4,5,6,7,8,9])
>>> G.add_nodes_from(H)
```

In addition to strings and integers any hashable Python object (except None) can represent a node, e.g. a customized node object, or even another Graph.

```
>>> G.add_node(H)
```

Edges:

G can also be grown by adding edges.

Add one edge,

```
>>> G.add_edge(1, 2)
```

a list of edges,

```
>>> G.add_edges_from([(1,2),(1,3)])
```

or a collection of edges,

```
>>> G.add_edges_from(H.edges())
```

If some edges connect nodes not yet in the graph, the nodes are added automatically. If an edge already exists, an additional edge is created and stored using a key to identify the edge. By default the key is the lowest unused integer.

```
>>> G.add_edges_from([(4,5,dict(route=282)), (4,5,dict(route=37))])
>>> G[4]
{5: {0: {}, 1: {'route': 282}, 2: {'route': 37}}}
```

Attributes:

Each graph, node, and edge can hold key/value attribute pairs in an associated attribute dictionary (the keys must be hashable). By default these are empty, but can be added or changed using `add_edge`, `add_node` or direct manipulation of the attribute dictionaries named `graph`, `node` and `edge` respectively.

```
>>> G = nx.MultiDiGraph(day="Friday")
>>> G.graph
{'day': 'Friday'}
```

Add node attributes using `add_node()`, `add_nodes_from()` or `G.node`

```
>>> G.add_node(1, time='5pm')
>>> G.add_nodes_from([3], time='2pm')
>>> G.node[1]
{'time': '5pm'}
>>> G.node[1]['room'] = 714
>>> del G.node[1]['room'] # remove attribute
>>> G.nodes(data=True)
[(1, {'time': '5pm'}), (3, {'time': '2pm'})]
```

Warning: adding a node to `G.node` does not add it to the graph.

Add edge attributes using `add_edge()`, `add_edges_from()`, subscript notation, or `G.edge`.

```
>>> G.add_edge(1, 2, weight=4.7)
>>> G.add_edges_from([(3,4), (4,5)], color='red')
>>> G.add_edges_from([(1,2,{'color':'blue'}), (2,3,{'weight':8})])
>>> G[1][2][0]['weight'] = 4.7
>>> G.edge[1][2][0]['weight'] = 4
```

Shortcuts:

Many common graph features allow python syntax to speed reporting.

```
>>> 1 in G # check if node in graph
True
>>> [n for n in G if n<3] # iterate through nodes
[1, 2]
>>> len(G) # number of nodes in graph
5
>>> G[1] # adjacency dict keyed by neighbor to edge attributes
... # Note: you should not change this dict manually!
{2: {0: {'weight': 4}, 1: {'color': 'blue'}}}
```

The fastest way to traverse all edges of a graph is via `adjacency_iter()`, but the `edges()` method is often more convenient.

```
>>> for n,nbrsdict in G.adjacency_iter():
...     for nbr,keydict in nbrsdict.items():
...         for key,eattr in keydict.items():
...             if 'weight' in eattr:
...                 (n,nbr,eattr['weight'])
```

```
(1, 2, 4)
(2, 3, 8)
>>> G.edges(data='weight')
[(1, 2, 4), (1, 2, None), (2, 3, 8), (3, 4, None), (4, 5, None)]
```

Reporting:

Simple graph information is obtained using methods. Iterator versions of many reporting methods exist for efficiency. Methods exist for reporting `nodes()`, `edges()`, `neighbors()` and `degree()` as well as the number of nodes and edges.

For details on these and other miscellaneous methods, see below.

Subclasses (Advanced):

The MultiDiGraph class uses a dict-of-dict-of-dict-of-dict structure. The outer dict (`node_dict`) holds adjacency lists keyed by node. The next dict (`adjlist`) represents the adjacency list and holds `edge_key` dicts keyed by neighbor. The `edge_key` dict holds each `edge_attr` dict keyed by edge key. The inner dict (`edge_attr`) represents the edge data and holds edge attribute values keyed by attribute names.

Each of these four dicts in the dict-of-dict-of-dict-of-dict structure can be replaced by a user defined dict-like object. In general, the dict-like features should be maintained but extra features can be added. To replace one of the dicts create a new graph class by changing the `class(!)` variable holding the factory for that dict-like structure. The variable names are `node_dict_factory`, `adjlist_dict_factory`, `edge_key_dict_factory` and `edge_attr_dict_factory`.

node_dict_factory [function, (default: dict)] Factory function to be used to create the outer-most dict in the data structure that holds adjacency lists keyed by node. It should require no arguments and return a dict-like object.

adjlist_dict_factory [function, (default: dict)] Factory function to be used to create the adjacency list dict which holds multiedge key dicts keyed by neighbor. It should require no arguments and return a dict-like object.

edge_key_dict_factory [function, (default: dict)] Factory function to be used to create the edge key dict which holds edge data keyed by edge key. It should require no arguments and return a dict-like object.

edge_attr_dict_factory [function, (default: dict)] Factory function to be used to create the edge attribute dict which holds attribute values keyed by attribute name. It should require no arguments and return a dict-like object.

Examples

Create a multigraph object that tracks the order nodes are added.

```
>>> from collections import OrderedDict
>>> class OrderedGraph(nx.MultiDiGraph):
...     node_dict_factory = OrderedDict
>>> G = OrderedGraph()
>>> G.add_nodes_from( (2,1) )
>>> G.nodes()
[2, 1]
>>> G.add_edges_from( ((2,2), (2,1), (2,1), (1,1)) )
>>> G.edges()
[(2, 1), (2, 1), (2, 2), (1, 1)]
```

Create a multidigraph object that tracks the order nodes are added and for each node track the order that neighbors are added and for each neighbor tracks the order that multiedges are added.

```
>>> class OrderedGraph(nx.MultiDiGraph):
...     node_dict_factory = OrderedDict
...     adjlist_dict_factory = OrderedDict
...     edge_key_dict_factory = OrderedDict
>>> G = OrderedGraph()
>>> G.add_nodes_from( (2,1) )
>>> G.nodes()
[2, 1]
>>> G.add_edges_from( ((2,2), (2,1,2,{'weight':0.1})), (2,1,1,{'weight':0.2})), (1,1)) )
>>> G.edges(keys=True)
[(2, 2, 0), (2, 1, 2), (2, 1, 1), (1, 1, 0)]
```

Adding and Removing Nodes and Edges

Iterating over nodes and edges

Information about graph structure

Making copies and subgraphs

ALGORITHMS

4.1 Approximation

4.1.1 Connectivity

Fast approximation for node connectivity

<code>all_pairs_node_connectivity(G[, nbunch, cutoff])</code>	Compute node connectivity between all pairs of nodes.
<code>local_node_connectivity(G, source, target[, ...])</code>	Compute node connectivity between source and target.
<code>node_connectivity(G[, s, t])</code>	Returns an approximation for node connectivity for a graph or digraph.

`all_pairs_node_connectivity`

`all_pairs_node_connectivity` (*G*, *nbunch=None*, *cutoff=None*)

Compute node connectivity between all pairs of nodes.

Pairwise or local node connectivity between two distinct and nonadjacent nodes is the minimum number of nodes that must be removed (minimum separating cutset) to disconnect them. By Menger's theorem, this is equal to the number of node independent paths (paths that share no nodes other than source and target). Which is what we compute in this function.

This algorithm is a fast approximation that gives an strict lower bound on the actual number of node independent paths between two nodes¹. It works for both directed and undirected graphs.

Parameters

- ***G*** (*NetworkX graph*) –
- ***nbunch*** (*container*) – Container of nodes. If provided node connectivity will be computed only over pairs of nodes in *nbunch*.
- ***cutoff*** (*integer*) – Maximum node connectivity to consider. If *None*, the minimum degree of source or target is used as a cutoff in each pair of nodes. Default value *None*.

Returns **K** – Dictionary, keyed by source and target, of pairwise node connectivity

Return type dictionary

See also:

`local_node_connectivity()`, `all_pairs_node_connectivity()`

¹ White, Douglas R., and Mark Newman. 2001 A Fast Algorithm for Node-Independent Paths. Santa Fe Institute Working Paper #01-07-035 <http://eclectic.ss.uci.edu/~drwhite/working.pdf>

References

local_node_connectivity

local_node_connectivity (*G*, *source*, *target*, *cutoff*=None)

Compute node connectivity between source and target.

Pairwise or local node connectivity between two distinct and nonadjacent nodes is the minimum number of nodes that must be removed (minimum separating cutset) to disconnect them. By Menger's theorem, this is equal to the number of node independent paths (paths that share no nodes other than source and target). Which is what we compute in this function.

This algorithm is a fast approximation that gives an strict lower bound on the actual number of node independent paths between two nodes². It works for both directed and undirected graphs.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node*) – Starting node for node connectivity
- **target** (*node*) – Ending node for node connectivity
- **cutoff** (*integer*) – Maximum node connectivity to consider. If None, the minimum degree of source or target is used as a cutoff. Default value None.

Returns **k** – pairwise node connectivity

Return type integer

Examples

```
>>> # Platonic icosahedral graph has node connectivity 5
>>> # for each non adjacent node pair
>>> from networkx.algorithms import approximation as approx
>>> G = nx.icosahedral_graph()
>>> approx.local_node_connectivity(G, 0, 6)
5
```

Notes

This algorithm¹ finds node independents paths between two nodes by computing their shortest path using BFS, marking the nodes of the path found as 'used' and then searching other shortest paths excluding the nodes marked as used until no more paths exist. It is not exact because a shortest path could use nodes that, if the path were longer, may belong to two different node independent paths. Thus it only guarantees an strict lower bound on node connectivity.

Note that the authors propose a further refinement, losing accuracy and gaining speed, which is not implemented yet.

See also:

`all_pairs_node_connectivity()`, `node_connectivity()`

² White, Douglas R., and Mark Newman. 2001 A Fast Algorithm for Node-Independent Paths. Santa Fe Institute Working Paper #01-07-035 <http://eclectic.ss.uci.edu/~drwhite/working.pdf>

References

node_connectivity

node_connectivity (*G*, *s=None*, *t=None*)

Returns an approximation for node connectivity for a graph or digraph *G*.

Node connectivity is equal to the minimum number of nodes that must be removed to disconnect *G* or render it trivial. By Menger's theorem, this is equal to the number of node independent paths (paths that share no nodes other than source and target).

If source and target nodes are provided, this function returns the local node connectivity: the minimum number of nodes that must be removed to break all paths from source to target in *G*.

This algorithm is based on a fast approximation that gives an strict lower bound on the actual number of node independent paths between two nodes³. It works for both directed and undirected graphs.

Parameters

- **G** (*NetworkX graph*) – Undirected graph
- **s** (*node*) – Source node. Optional. Default value: None.
- **t** (*node*) – Target node. Optional. Default value: None.

Returns **K** – Node connectivity of *G*, or local node connectivity if source and target are provided.

Return type integer

Examples

```
>>> # Platonic icosahedral graph is 5-node-connected
>>> from networkx.algorithms import approximation as approx
>>> G = nx.icosahedral_graph()
>>> approx.node_connectivity(G)
5
```

Notes

This algorithm¹ finds node independent paths between two nodes by computing their shortest path using BFS, marking the nodes of the path found as 'used' and then searching other shortest paths excluding the nodes marked as used until no more paths exist. It is not exact because a shortest path could use nodes that, if the path were longer, may belong to two different node independent paths. Thus it only guarantees an strict lower bound on node connectivity.

See also:

`all_pairs_node_connectivity()`, `local_node_connectivity()`

References

4.1.2 K-components

Fast approximation for k-component structure

³ White, Douglas R., and Mark Newman. 2001 A Fast Algorithm for Node-Independent Paths. Santa Fe Institute Working Paper #01-07-035 <http://eclectic.ss.uci.edu/~drwhite/working.pdf>

`k_components(G[, min_density])` Returns the approximate k-component structure of a graph G.

k_components

k_components (*G*, *min_density*=0.95)

Returns the approximate k-component structure of a graph G.

A *k*-component is a maximal subgraph of a graph G that has, at least, node connectivity *k*: we need to remove at least *k* nodes to break it into more components. *k*-components have an inherent hierarchical structure because they are nested in terms of connectivity: a connected graph can contain several 2-components, each of which can contain one or more 3-components, and so forth.

This implementation is based on the fast heuristics to approximate the *k*-component structure of a graph ⁴. Which, in turn, it is based on a fast approximation algorithm for finding good lower bounds of the number of node independent paths between two nodes ⁵.

Parameters

- **G** (*NetworkX graph*) – Undirected graph
- **min_density** (*Float*) – Density relaxation threshold. Default value 0.95

Returns **k_components** – Dictionary with connectivity level *k* as key and a list of sets of nodes that form a k-component of level *k* as values.

Return type **dict**

Examples

```
>>> # Petersen graph has 10 nodes and it is triconnected, thus all
>>> # nodes are in a single component on all three connectivity levels
>>> from networkx.algorithms import approximation as apxa
>>> G = nx.petersen_graph()
>>> k_components = apxa.k_components(G)
```

Notes

The logic of the approximation algorithm for computing the *k*-component structure ¹ is based on repeatedly applying simple and fast algorithms for *k*-cores and biconnected components in order to narrow down the number of pairs of nodes over which we have to compute White and Newman's approximation algorithm for finding node independent paths ². More formally, this algorithm is based on Whitney's theorem, which states an inclusion relation among node connectivity, edge connectivity, and minimum degree for any graph G. This theorem implies that every *k*-component is nested inside a *k*-edge-component, which in turn, is contained in a *k*-core. Thus, this algorithm computes node independent paths among pairs of nodes in each biconnected part of each *k*-core, and repeats this procedure for each *k* from 3 to the maximal core number of a node in the input graph.

Because, in practice, many nodes of the core of level *k* inside a bicomponent actually are part of a component of level *k*, the auxiliary graph needed for the algorithm is likely to be very dense. Thus, we use a complement graph data structure (see *AntiGraph*) to save memory. *AntiGraph* only stores information of the edges that are

⁴ Torrents, J. and F. Ferraro (2015) Structural Cohesion: Visualization and Heuristics for Fast Computation. <http://arxiv.org/pdf/1503.04476v1>

⁵ White, Douglas R., and Mark Newman (2001) A Fast Algorithm for Node-Independent Paths. Santa Fe Institute Working Paper #01-07-035 <http://eclectic.ss.uci.edu/~drwhite/working.pdf>

not present in the actual auxiliary graph. When applying algorithms to this complement graph data structure, it behaves as if it were the dense version.

See also:

`k_components()`

References

4.1.3 Clique

Cliques.

<code>max_clique(G)</code>	Find the Maximum Clique
<code>clique_removal(G)</code>	Repeatedly remove cliques from the graph.

max_clique

max_clique(*G*)

Find the Maximum Clique

Finds the $O(|V|/(\log|V|)^2)$ apx of maximum clique/independent set in the worst case.

Parameters *G* (*NetworkX graph*) – Undirected graph

Returns

- **clique** (*set*) – The apx-maximum clique of the graph
- *Notes*
- —
- *A clique in an undirected graph $G = (V, E)$ is a subset of the vertex set*
- *$C \subseteq V$, such that for every two vertices in C , there exists an edge*
- *connecting the two. This is equivalent to saying that the subgraph*
- *induced by C is complete (in some cases, the term clique may also refer*
- *to the subgraph).*
- *A maximum clique is a clique of the largest possible size in a given graph.*
- The clique number $\omega(G)$ of a graph G is the number of
- *vertices in a maximum clique in G . The intersection number of*
- *G is the smallest number of cliques that together cover all edges of G .*
- **http** ([//en.wikipedia.org/wiki/Maximum_clique](http://en.wikipedia.org/wiki/Maximum_clique))

References

clique_removal

clique_removal(*G*)

Repeatedly remove cliques from the graph.

Results in a $O(|V|/(\log |V|)^2)$ approximation of maximum clique & independent set. Returns the largest independent set found, along with found maximal cliques.

Parameters *G* (*NetworkX graph*) – Undirected graph

Returns *max_ind_cliques* – Maximal independent set and list of maximal cliques (sets) in the graph.

Return type (set, list) tuple

References

4.1.4 Clustering

<code>average_clustering(G[, trials])</code>	Estimates the average clustering coefficient of <i>G</i> .
--	--

average_clustering

average_clustering (*G*, *trials*=1000)

Estimates the average clustering coefficient of *G*.

The local clustering of each node in *G* is the fraction of triangles that actually exist over all possible triangles in its neighborhood. The average clustering coefficient of a graph *G* is the mean of local clusterings.

This function finds an approximate average clustering coefficient for *G* by repeating *n* times (defined in *trials*) the following experiment: choose a node at random, choose two of its neighbors at random, and check if they are connected. The approximate coefficient is the fraction of triangles found over the number of trials ⁶.

Parameters

- *G* (*NetworkX graph*) –
- **trials** (*integer*) – Number of trials to perform (default 1000).

Returns *c* – Approximated average clustering coefficient.

Return type float

References

4.1.5 Dominating Set

Functions for finding node and edge dominating sets.

A ‘dominating set’_[1] for an undirected graph **G* with vertex set *V* and edge set *E* is a subset *D* of *V* such that every vertex not in *D* is adjacent to at least one member of *D*. An ‘edge dominating set’_[2] is a subset **F* of *E* such that every edge not in *F* is incident to an endpoint of at least one edge in *F*.

<code>min_weighted_dominating_set(G[, weight])</code>	Returns a dominating set that approximates the minimum weight node domin
<code>min_edge_dominating_set(G)</code>	Return minimum cardinality edge dominating set.

⁶ Schank, Thomas, and Dorothea Wagner. Approximating clustering coefficient and transitivity. Universität Karlsruhe, Fakultät für Informatik, 2004. <http://www.emis.ams.org/journals/JGAA/accepted/2005/SchankWagner2005.9.2.pdf>

min_weighted_dominating_set

min_weighted_dominating_set (*G*, *weight=None*)

Returns a dominating set that approximates the minimum weight node dominating set.

Parameters

- **G** (*NetworkX graph*) – Undirected graph.
- **weight** (*string*) – The node attribute storing the weight of an edge. If provided, the node attribute with this key must be a number for each node. If not provided, each node is assumed to have weight one.

Returns min_weight_dominating_set – A set of nodes, the sum of whose weights is no more than $(\log w(V))w(V^*)$, where $w(V)$ denotes the sum of the weights of each node in the graph and $w(V^*)$ denotes the sum of the weights of each node in the minimum weight dominating set.

Return type `set`

Notes

This algorithm computes an approximate minimum weighted dominating set for the graph G . The returned solution has weight $(\log w(V))w(V^*)$, where $w(V)$ denotes the sum of the weights of each node in the graph and $w(V^*)$ denotes the sum of the weights of each node in the minimum weight dominating set for the graph.

This implementation of the algorithm runs in $O(m)$ time, where m is the number of edges in the graph.

References

min_edge_dominating_set

min_edge_dominating_set (*G*)

Return minimum cardinality edge dominating set.

Parameters **G** (*NetworkX graph*) – Undirected graph

Returns min_edge_dominating_set – Returns a set of dominating edges whose size is no more than $2 * \text{OPT}$.

Return type `set`

Notes

The algorithm computes an approximate solution to the edge dominating set problem. The result is no more than $2 * \text{OPT}$ in terms of size of the set. Runtime of the algorithm is $O(|E|)$.

4.1.6 Independent Set

Independent Set

Independent set or stable set is a set of vertices in a graph, no two of which are adjacent. That is, it is a set I of vertices such that for every two vertices in I , there is no edge connecting the two. Equivalently, each edge in the graph has at most one endpoint in I . The size of an independent set is the number of vertices it contains.

A maximum independent set is a largest independent set for a given graph G and its size is denoted $\alpha(G)$. The problem of finding such a set is called the maximum independent set problem and is an NP-hard optimization problem. As such, it is unlikely that there exists an efficient algorithm for finding a maximum independent set of a graph.

[http://en.wikipedia.org/wiki/Independent_set_\(graph_theory\)](http://en.wikipedia.org/wiki/Independent_set_(graph_theory))

Independent set algorithm is based on the following paper:

$O(|V|/(log|V|)^2)$ apx of maximum clique/independent set.

Boppana, R., & Halldórsson, M. M. (1992). Approximating maximum independent sets by excluding subgraphs. BIT Numerical Mathematics, 32(2), 180–196. Springer. doi:10.1007/BF01994876

`maximum_independent_set(G)` Return an approximate maximum independent set.

maximum_independent_set

maximum_independent_set (G)

Return an approximate maximum independent set.

Parameters G (*NetworkX graph*) – Undirected graph

Returns `iset` – The apx-maximum independent set

Return type Set

Notes

Finds the $O(|V|/(log|V|)^2)$ apx of independent set in the worst case.

References

4.1.7 Matching

Graph Matching

Given a graph $G = (V, E)$, a matching M in G is a set of pairwise non-adjacent edges; that is, no two edges share a common vertex.

[http://en.wikipedia.org/wiki/Matching_\(graph_theory\)](http://en.wikipedia.org/wiki/Matching_(graph_theory))

`min_maximal_matching(G)` Returns the minimum maximal matching of G .

min_maximal_matching

min_maximal_matching (G)

Returns the minimum maximal matching of G . That is, out of all maximal matchings of the graph G , the smallest is returned.

Parameters G (*NetworkX graph*) – Undirected graph

Returns `min_maximal_matching` – Returns a set of edges such that no two edges share a common endpoint and every edge not in the set shares some common endpoint in the set. Cardinality will be $2 \cdot \text{OPT}$ in the worst case.

Return type `set`

Notes

The algorithm computes an approximate solution for the minimum maximal cardinality matching problem. The solution is no more than $2 * \text{OPT}$ in size. Runtime is $O(|E|)$.

References

4.1.8 Ramsey

Ramsey numbers.

`ramsey_R2(G)` Approximately computes the Ramsey number $R(2; s, t)$ for graph.

ramsey_R2

ramsey_R2 (*G*)

Approximately computes the Ramsey number $R(2; s, t)$ for graph.

Parameters *G* (*NetworkX graph*) – Undirected graph

Returns `max_pair` – Maximum clique, Maximum independent set.

Return type (set, set) tuple

4.1.9 Vertex Cover

Vertex Cover

Given an undirected graph $G = (V, E)$ and a function *w* assigning nonnegative weights to its vertices, find a minimum weight subset of *V* such that each edge in *E* is incident to at least one vertex in the subset.

http://en.wikipedia.org/wiki/Vertex_cover

`min_weighted_vertex_cover(G[, weight])` 2-OPT Local Ratio for Minimum Weighted Vertex Cover

min_weighted_vertex_cover

min_weighted_vertex_cover (*G*, *weight=None*)

2-OPT Local Ratio for Minimum Weighted Vertex Cover

Find an approximate minimum weighted vertex cover of a graph.

Parameters

- *G* (*NetworkX graph*) – Undirected graph
- **weight** (*None or string, optional (default = None)*) – If *None*, every edge has weight/distance/cost 1. If a string, use this edge attribute as the edge weight. Any edge attribute not present defaults to 1.

Returns `min_weighted_cover` – Returns a set of vertices whose weight sum is no more than $2 *$

OPT.

Return type `set`

Notes

Local-Ratio algorithm for computing an approximate vertex cover. Algorithm greedily reduces the costs over edges and iteratively builds a cover. Worst-case runtime is $O(|E|)$.

References

4.2 Assortativity

4.2.1 Assortativity

4.2.2 Average neighbor degree

4.2.3 Average degree connectivity

4.2.4 Mixing

4.3 Bipartite

This module provides functions and operations for bipartite graphs. Bipartite graphs $B = (U, V, E)$ have two node sets U, V and edges in E that only connect nodes from opposite sets. It is common in the literature to use an spatial analogy referring to the two node sets as top and bottom nodes.

The bipartite algorithms are not imported into the `networkx` namespace at the top level so the easiest way to use them is with:

```
>>> import networkx as nx
>>> from networkx.algorithms import bipartite
```

NetworkX does not have a custom bipartite graph class but the `Graph()` or `DiGraph()` classes can be used to represent bipartite graphs. However, you have to keep track of which set each node belongs to, and make sure that there is no edge between nodes of the same set. The convention used in NetworkX is to use a node attribute named “bipartite” with values 0 or 1 to identify the sets each node belongs to.

For example:


```
>>> B = nx.Graph()
>>> B.add_nodes_from([1,2,3,4], bipartite=0) # Add the node attribute "bipartite"
>>> B.add_nodes_from(['a', 'b', 'c'], bipartite=1)
>>> B.add_edges_from([(1, 'a'), (1, 'b'), (2, 'b'), (2, 'c'), (3, 'c'), (4, 'a')])
```

Many algorithms of the bipartite module of NetworkX require, as an argument, a container with all the nodes that belong to one set, in addition to the bipartite graph *B*. If *B* is connected, you can find the node sets using a two-coloring algorithm:

```
>>> nx.is_connected(B)
True
>>> bottom_nodes, top_nodes = bipartite.sets(B)
```

```
list(top_nodes) [1, 2, 3, 4] list(bottom_nodes) ['a', 'c', 'b']
```

However, if the input graph is not connected, there are more than one possible colorations. Thus, the following result is correct:

```
>>> B.remove_edge(2, 'c')
>>> nx.is_connected(B)
False
>>> bottom_nodes, top_nodes = bipartite.sets(B)
```

```
list(top_nodes) [1, 2, 4, 'c'] list(bottom_nodes) ['a', 3, 'b']
```

Using the “bipartite” node attribute, you can easily get the two node sets:

```
>>> top_nodes = set(n for n,d in B.nodes(data=True) if d['bipartite']==0)
>>> bottom_nodes = set(B) - top_nodes
```

```
list(top_nodes) [1, 2, 3, 4] list(bottom_nodes) ['a', 'c', 'b']
```

So you can easily use the bipartite algorithms that require, as an argument, a container with all nodes that belong to one node set:

```
>>> print(round(bipartite.density(B, bottom_nodes), 2))
0.42
>>> G = bipartite.projected_graph(B, top_nodes)
>>> G.edges()
[(1, 2), (1, 4)]
```

All bipartite graph generators in NetworkX build bipartite graphs with the “bipartite” node attribute. Thus, you can use the same approach:

```
>>> RB = bipartite.random_graph(5, 7, 0.2)
>>> RB_top = set(n for n,d in RB.nodes(data=True) if d['bipartite']==0)
>>> RB_bottom = set(RB) - RB_top
>>> list(RB_top)
[0, 1, 2, 3, 4]
>>> list(RB_bottom)
[5, 6, 7, 8, 9, 10, 11]
```

For other bipartite graph generators see the bipartite section of [Graph generators](#).

4.3.1 Basic functions

Bipartite Graph Algorithms

<code>is_bipartite(G)</code>	Returns True if graph G is bipartite, False if not.
<code>is_bipartite_node_set(G, nodes)</code>	Returns True if nodes and G/nodes are a bipartition of G.
<code>sets(G)</code>	Returns bipartite node sets of graph G.
<code>color(G)</code>	Returns a two-coloring of the graph.
<code>density(B, nodes)</code>	Return density of bipartite graph B.
<code>degrees(B, nodes[, weight])</code>	Return the degrees of the two node sets in the bipartite graph B.

is_bipartite

`is_bipartite(G)`

Returns True if graph G is bipartite, False if not.

Parameters *G* (*NetworkX graph*) –

Examples

```
>>> from networkx.algorithms import bipartite
>>> G = nx.path_graph(4)
>>> print(bipartite.is_bipartite(G))
True
```

See also:

`color()`, `is_bipartite_node_set()`

is_bipartite_node_set

`is_bipartite_node_set(G, nodes)`

Returns True if nodes and G/nodes are a bipartition of G.

Parameters

- *G* (*NetworkX graph*) –
- *nodes* (*list or container*) – Check if nodes are a one of a bipartite set.

Examples

```
>>> from networkx.algorithms import bipartite
>>> G = nx.path_graph(4)
>>> X = set([1, 3])
>>> bipartite.is_bipartite_node_set(G, X)
True
```

Notes

For connected graphs the bipartite sets are unique. This function handles disconnected graphs.

sets

sets(*G*)

Returns bipartite node sets of graph *G*.

Raises an exception if the graph is not bipartite.

Parameters *G* (*NetworkX graph*) –

Returns (*X,Y*) – One set of nodes for each part of the bipartite graph.

Return type two-tuple of sets

Examples

```
>>> from networkx.algorithms import bipartite
>>> G = nx.path_graph(4)
>>> X, Y = bipartite.sets(G)
>>> list(X)
[0, 2]
>>> list(Y)
[1, 3]
```

See also:

`color()`

color

color(*G*)

Returns a two-coloring of the graph.

Raises an exception if the graph is not bipartite.

Parameters *G* (*NetworkX graph*) –

Returns **color** – A dictionary keyed by node with a 1 or 0 as data for each node color.

Return type dictionary

Raises **NetworkXError** if the graph is not two-colorable. –

Examples

```
>>> from networkx.algorithms import bipartite
>>> G = nx.path_graph(4)
>>> c = bipartite.color(G)
>>> print(c)
{0: 1, 1: 0, 2: 1, 3: 0}
```

You can use this to set a node attribute indicating the bipartite set:

```
>>> nx.set_node_attributes(G, 'bipartite', c)
>>> print(G.node[0]['bipartite'])
1
>>> print(G.node[1]['bipartite'])
0
```

density

density (*B, nodes*)

Return density of bipartite graph B.

Parameters

- **G** (*NetworkX graph*) –
- **nodes** (*list or container*) – Nodes in one set of the bipartite graph.

Returns **d** – The bipartite density

Return type `float`

Examples

```
>>> from networkx.algorithms import bipartite
>>> G = nx.complete_bipartite_graph(3,2)
>>> X=set([0,1,2])
>>> bipartite.density(G,X)
1.0
>>> Y=set([3,4])
>>> bipartite.density(G,Y)
1.0
```

See also:

`color()`

degrees

degrees (*B, nodes, weight=None*)

Return the degrees of the two node sets in the bipartite graph B.

Parameters

- **G** (*NetworkX graph*) –
- **nodes** (*list or container*) – Nodes in one set of the bipartite graph.
- **weight** (*string or None, optional (default=None)*) – The edge attribute that holds the numerical value used as a weight. If None, then each edge has weight 1. The degree is the sum of the edge weights adjacent to the node.

Returns (**degX,degY**) – The degrees of the two bipartite sets as dictionaries keyed by node.

Return type tuple of dictionaries

Examples

```
>>> from networkx.algorithms import bipartite
>>> G = nx.complete_bipartite_graph(3,2)
>>> Y=set([3,4])
>>> degX,degY=bipartite.degrees(G,Y)
>>> degX
{0: 2, 1: 2, 2: 2}
```

See also:

`color()`, `density()`

4.3.2 Matching

Provides functions for computing a maximum cardinality matching in a bipartite graph.

If you don't care about the particular implementation of the maximum matching algorithm, simply use the `maximum_matching()`. If you do care, you can import one of the named maximum matching algorithms directly.

For example, to find a maximum matching in the complete bipartite graph with two vertices on the left and three vertices on the right:

```
>>> import networkx as nx
>>> G = nx.complete_bipartite_graph(2, 3)
>>> left, right = nx.bipartite.sets(G)
>>> list(left)
[0, 1]
>>> list(right)
[2, 3, 4]
>>> nx.bipartite.maximum_matching(G)
{0: 2, 1: 3, 2: 0, 3: 1}
```

The dictionary returned by `maximum_matching()` includes a mapping for vertices in both the left and right vertex sets.

<code>eppstein_matching(G)</code>	Returns the maximum cardinality matching of the bipartite graph G .
<code>hopcroft_karp_matching(G)</code>	Returns the maximum cardinality matching of the bipartite graph G .
<code>to_vertex_cover(G, matching)</code>	Returns the minimum vertex cover corresponding to the given maximum matching of the bipartite graph G .

eppstein_matching

eppstein_matching(G)

Returns the maximum cardinality matching of the bipartite graph G .

Parameters G (*NetworkX graph*) – Undirected bipartite graph

Returns

matches –

The matching is returned as a dictionary, *matches*, such that `matches[v] == w` if node v is matched to node w . Unmatched nodes do not occur as a key in *mate*.

Return type dictionary

Notes

This function is implemented with David Eppstein's version of the algorithm Hopcroft–Karp algorithm (see `hopcroft_karp_matching()`), which originally appeared in the [Python Algorithms and Data Structures library](#) (PADS).

See also:

`hopcroft_karp_matching()`

hopcroft_karp_matching

hopcroft_karp_matching (*G*)

Returns the maximum cardinality matching of the bipartite graph *G*.

Parameters *G* (*NetworkX graph*) – Undirected bipartite graph

Returns

matches –

The matching is returned as a dictionary, *matches*, such that *matches*[*v*] == *w* if node *v* is matched to node *w*. Unmatched nodes do not occur as a key in *mate*.

Return type dictionary

Notes

This function is implemented with the [Hopcroft–Karp matching algorithm](#) for bipartite graphs.

See also:

[`eppstein_matching\(\)`](#)

References

to_vertex_cover

to_vertex_cover (*G*, *matching*)

Returns the minimum vertex cover corresponding to the given maximum matching of the bipartite graph *G*.

Parameters

- *G* (*NetworkX graph*) – Undirected bipartite graph
- **matching** (*dictionary*) – A dictionary whose keys are vertices in *G* and whose values are the distinct neighbors comprising the maximum matching for *G*, as returned by, for example, [`maximum_matching\(\)`](#). The dictionary *must* represent the maximum matching.

Returns

vertex_cover –

The minimum vertex cover in *G*.

Return type set

Notes

This function is implemented using the procedure guaranteed by [Konig's theorem](#), which proves an equivalence between a maximum matching and a minimum vertex cover in bipartite graphs.

Since a minimum vertex cover is the complement of a maximum independent set for any graph, one can compute the maximum independent set of a bipartite graph this way:

```
>>> import networkx as nx
>>> G = nx.complete_bipartite_graph(2, 3)
>>> matching = nx.bipartite.maximum_matching(G)
>>> vertex_cover = nx.bipartite.to_vertex_cover(G, matching)
```

```
>>> independent_set = set(G) - vertex_cover
>>> print(list(independent_set))
[2, 3, 4]
```

4.3.3 Matrix

Biadjacency matrices

<code>biadjacency_matrix(G, row_order[, ...])</code>	Return the biadjacency matrix of the bipartite graph G.
<code>from_biadjacency_matrix(A[, create_using, ...])</code>	Creates a new bipartite graph from a biadjacency matrix given as a SciPy s

biadjacency_matrix

biadjacency_matrix (*G*, *row_order*, *column_order*=None, *dtype*=None, *weight*='weight', *format*='csr')

Return the biadjacency matrix of the bipartite graph G.

Let $G = (U, V, E)$ be a bipartite graph with node sets $U = u_1, \dots, u_r$ and $V = v_1, \dots, v_s$. The biadjacency matrix ⁷ is the $r \times s$ matrix B in which $b_{i,j} = 1$ if, and only if, $(u_i, v_j) \in E$. If the parameter *weight* is not None and matches the name of an edge attribute, its value is used instead of 1.

Parameters

- **G** (*graph*) – A NetworkX graph
- **row_order** (*list of nodes*) – The rows of the matrix are ordered according to the list of nodes.
- **column_order** (*list, optional*) – The columns of the matrix are ordered according to the list of nodes. If *column_order* is None, then the ordering of columns is arbitrary.
- **dtype** (*NumPy data-type, optional*) – A valid NumPy dtype used to initialize the array. If None, then the NumPy default is used.
- **weight** (*string or None, optional (default='weight')*) – The edge data key used to provide each value in the matrix. If None, then each edge has weight 1.
- **format** (*str in {'bsr', 'csr', 'csc', 'coo', 'lil', 'dia', 'dok'}*) – The type of the matrix to be returned (default 'csr'). For some algorithms different implementations of sparse matrices can perform better. See ⁸ for details.

Returns **M** – Biadjacency matrix representation of the bipartite graph G.

Return type SciPy sparse matrix

Notes

No attempt is made to check that the input graph is bipartite.

For directed bipartite graphs only successors are considered as neighbors. To obtain an adjacency matrix with ones (or weight values) for both predecessors and successors you have to generate two biadjacency matrices where the rows of one of them are the columns of the other, and then add one to the transpose of the other.

See also:

`adjacency_matrix()`, `from_biadjacency_matrix()`

⁷ http://en.wikipedia.org/wiki/Adjacency_matrix#Adjacency_matrix_of_a_bipartite_graph

⁸ SciPy Dev. References, "Sparse Matrices", <http://docs.scipy.org/doc/scipy/reference/sparse.html>

References

from_biadjacency_matrix

from_biadjacency_matrix (*A*, *create_using=None*, *edge_attribute='weight'*)

Creates a new bipartite graph from a biadjacency matrix given as a SciPy sparse matrix.

Parameters

- **A** (*scipy sparse matrix*) – A biadjacency matrix representation of a graph
- **create_using** (*NetworkX graph*) – Use specified graph for result. The default is Graph()
- **edge_attribute** (*string*) – Name of edge attribute to store matrix numeric value. The data will have the same type as the matrix entry (int, float, (real,imag)).

Notes

The nodes are labeled with the attribute *bipartite* set to an integer 0 or 1 representing membership in part 0 or part 1 of the bipartite graph.

If *create_using* is an instance of `networkx.MultiGraph` or `networkx.MultiDiGraph` and the entries of *A* are of type `int`, then this function returns a multigraph (of the same type as *create_using*) with parallel edges. In this case, *edge_attribute* will be ignored.

See also:

`biadjacency_matrix()`, `from_numpy_matrix()`

References

[1] http://en.wikipedia.org/wiki/Adjacency_matrix#Adjacency_matrix_of_a_bipartite_graph

4.3.4 Projections

One-mode (unipartite) projections of bipartite graphs.

<code>projected_graph(B, nodes[, multigraph])</code>	Returns the projection of B onto one of its node sets.
<code>weighted_projected_graph(B, nodes[, ratio])</code>	Returns a weighted projection of B onto one of its node sets.
<code>collaboration_weighted_projected_graph(B, nodes)</code>	Newman's weighted projection of B onto one of its node sets.
<code>overlap_weighted_projected_graph(B, nodes[, ...])</code>	Overlap weighted projection of B onto one of its node sets.
<code>generic_weighted_projected_graph(B, nodes[, ...])</code>	Weighted projection of B with a user-specified weight function.

projected_graph

projected_graph (*B*, *nodes*, *multigraph=False*)

Returns the projection of B onto one of its node sets.

Returns the graph G that is the projection of the bipartite graph B onto the specified nodes. They retain their attributes and are connected in G if they have a common neighbor in B.

Parameters

- **B** (*NetworkX graph*) – The input graph should be bipartite.

- **nodes** (*list or iterable*) – Nodes to project onto (the “bottom” nodes).
- **multigraph** (*bool (default=False)*) – If True return a multigraph where the multiple edges represent multiple shared neighbors. The edge key in the multigraph is assigned to the label of the neighbor.

Returns Graph – A graph that is the projection onto the given nodes.

Return type NetworkX graph or multigraph

Examples

```
>>> from networkx.algorithms import bipartite
>>> B = nx.path_graph(4)
>>> G = bipartite.projected_graph(B, [1,3])
>>> print(G.nodes())
[1, 3]
>>> print(G.edges())
[(1, 3)]
```

If nodes *a*, and *b* are connected through both nodes 1 and 2 then building a multigraph results in two edges in the projection onto [*a*,*b*]:

```
>>> B = nx.Graph()
>>> B.add_edges_from([('a', 1), ('b', 1), ('a', 2), ('b', 2)])
>>> G = bipartite.projected_graph(B, ['a', 'b'], multigraph=True)
>>> print([sorted((u,v)) for u,v in G.edges()])
[['a', 'b'], ['a', 'b']]
```

No attempt is made to verify that the input graph *B* is bipartite. Returns a simple graph that is the projection of the bipartite graph *B* onto the set of nodes given in list *nodes*. If *multigraph=True* then a multigraph is returned with an edge for every shared neighbor.

Directed graphs are allowed as input. The output will also then be a directed graph with edges if there is a directed path between the nodes.

The graph and node properties are (shallow) copied to the projected graph.

See also:

`is_bipartite()`, `is_bipartite_node_set()`, `sets()`, `weighted_projected_graph()`, `collaboration_weighted_projected_graph()`, `overlap_weighted_projected_graph()`, `generic_weighted_projected_graph()`

weighted_projected_graph

weighted_projected_graph (*B, nodes, ratio=False*)

Returns a weighted projection of *B* onto one of its node sets.

The weighted projected graph is the projection of the bipartite network *B* onto the specified nodes with weights representing the number of shared neighbors or the ratio between actual shared neighbors and possible shared neighbors if *ratio=True*⁹. The nodes retain their attributes and are connected in the resulting graph if they have an edge to a common node in the original graph.

Parameters

- **B** (*NetworkX graph*) – The input graph should be bipartite.

⁹ Borgatti, S.P. and Halgin, D. In press. “Analyzing Affiliation Networks”. In Carrington, P. and Scott, J. (eds) The Sage Handbook of Social Network Analysis. Sage Publications.

- **nodes** (*list or iterable*) – Nodes to project onto (the “bottom” nodes).
- **ratio** (*Bool (default=False)*) – If True, edge weight is the ratio between actual shared neighbors and possible shared neighbors. If False, edges weight is the number of shared neighbors.

Returns Graph – A graph that is the projection onto the given nodes.

Return type NetworkX graph

Examples

```
>>> from networkx.algorithms import bipartite
>>> B = nx.path_graph(4)
>>> G = bipartite.weighted_projected_graph(B, [1,3])
>>> print(G.nodes())
[1, 3]
>>> print(G.edges(data=True))
[(1, 3, {'weight': 1})]
>>> G = bipartite.weighted_projected_graph(B, [1,3], ratio=True)
>>> print(G.edges(data=True))
[(1, 3, {'weight': 0.5})]
```

No attempt is made to verify that the input graph B is bipartite. The graph and node properties are (shallow) copied to the projected graph.

See also:

`is_bipartite()`, `is_bipartite_node_set()`, `sets()`, `collaboration_weighted_projected_graph()`, `overlap_weighted_projected_graph()`, `generic_weighted_projected_graph()`, `projected_graph()`

References

collaboration_weighted_projected_graph

collaboration_weighted_projected_graph (*B, nodes*)

Newman’s weighted projection of B onto one of its node sets.

The collaboration weighted projection is the projection of the bipartite network B onto the specified nodes with weights assigned using Newman’s collaboration model ¹⁰:

$$w_{v,u} = \sum_k \frac{\delta_v^w \delta_w^k}{k_w - 1}$$

where *v* and *u* are nodes from the same bipartite node set, and *w* is a node of the opposite node set. The value k_w is the degree of node *w* in the bipartite network and δ_v^w is 1 if node *v* is linked to node *w* in the original bipartite graph or 0 otherwise.

The nodes retain their attributes and are connected in the resulting graph if have an edge to a common node in the original bipartite graph.

Parameters

- **B** (*NetworkX graph*) – The input graph should be bipartite.
- **nodes** (*list or iterable*) – Nodes to project onto (the “bottom” nodes).

¹⁰ Scientific collaboration networks: II. Shortest paths, weighted networks, and centrality, M. E. J. Newman, Phys. Rev. E 64, 016132 (2001).

Returns Graph – A graph that is the projection onto the given nodes.

Return type NetworkX graph

Examples

```
>>> from networkx.algorithms import bipartite
>>> B = nx.path_graph(5)
>>> B.add_edge(1,5)
>>> G = bipartite.collaboration_weighted_projected_graph(B, [0, 2, 4, 5])
>>> print(G.nodes())
[0, 2, 4, 5]
>>> for edge in G.edges(data=True): print(edge)
...
(0, 2, {'weight': 0.5})
(0, 5, {'weight': 0.5})
(2, 4, {'weight': 1.0})
(2, 5, {'weight': 0.5})
```

No attempt is made to verify that the input graph B is bipartite. The graph and node properties are (shallow) copied to the projected graph.

See also:

`is_bipartite()`, `is_bipartite_node_set()`, `sets()`, `weighted_projected_graph()`, `overlap_weighted_projected_graph()`, `generic_weighted_projected_graph()`, `projected_graph()`

References

overlap_weighted_projected_graph

overlap_weighted_projected_graph(*B*, *nodes*, *jaccard*=True)

Overlap weighted projection of B onto one of its node sets.

The overlap weighted projection is the projection of the bipartite network B onto the specified nodes with weights representing the Jaccard index between the neighborhoods of the two nodes in the original bipartite network¹¹:

$$w_{v,u} = \frac{|N(u) \cap N(v)|}{|N(u) \cup N(v)|}$$

or if the parameter ‘jaccard’ is False, the fraction of common neighbors by minimum of both nodes degree in the original bipartite graph¹:

$$w_{v,u} = \frac{|N(u) \cap N(v)|}{\min(|N(u)|, |N(v)|)}$$

The nodes retain their attributes and are connected in the resulting graph if have an edge to a common node in the original bipartite graph.

Parameters

- **B** (*NetworkX graph*) – The input graph should be bipartite.
- **nodes** (*list or iterable*) – Nodes to project onto (the “bottom” nodes).

¹¹ Borgatti, S.P. and Halgin, D. In press. Analyzing Affiliation Networks. In Carrington, P. and Scott, J. (eds) The Sage Handbook of Social Network Analysis. Sage Publications.

- **jaccard** (*Bool (default=True)*) –

Returns Graph – A graph that is the projection onto the given nodes.

Return type NetworkX graph

Examples

```
>>> from networkx.algorithms import bipartite
>>> B = nx.path_graph(5)
>>> G = bipartite.overlap_weighted_projected_graph(B, [0, 2, 4])
>>> print(G.nodes())
[0, 2, 4]
>>> print(G.edges(data=True))
[(0, 2, {'weight': 0.5}), (2, 4, {'weight': 0.5})]
>>> G = bipartite.overlap_weighted_projected_graph(B, [0, 2, 4], jaccard=False)
>>> print(G.edges(data=True))
[(0, 2, {'weight': 1.0}), (2, 4, {'weight': 1.0})]
```

No attempt is made to verify that the input graph B is bipartite. The graph and node properties are (shallow) copied to the projected graph.

See also:

`is_bipartite()`, `is_bipartite_node_set()`, `sets()`, `weighted_projected_graph()`, `collaboration_weighted_projected_graph()`, `generic_weighted_projected_graph()`, `projected_graph()`

References

generic_weighted_projected_graph

generic_weighted_projected_graph (*B, nodes, weight_function=None*)

Weighted projection of B with a user-specified weight function.

The bipartite network B is projected on to the specified nodes with weights computed by a user-specified function. This function must accept as a parameter the neighborhood sets of two nodes and return an integer or a float.

The nodes retain their attributes and are connected in the resulting graph if they have an edge to a common node in the original graph.

Parameters

- **B** (*NetworkX graph*) – The input graph should be bipartite.
- **nodes** (*list or iterable*) – Nodes to project onto (the “bottom” nodes).
- **weight_function** (*function*) – This function must accept as parameters the same input graph that this function, and two nodes; and return an integer or a float. The default function computes the number of shared neighbors.

Returns Graph – A graph that is the projection onto the given nodes.

Return type NetworkX graph

Examples

```
>>> from networkx.algorithms import bipartite
>>> # Define some custom weight functions
>>> def jaccard(G, u, v):
...     unbrs = set(G[u])
...     vnbrs = set(G[v])
...     return float(len(unbrs & vnbrs)) / len(unbrs | vnbrs)
...
>>> def my_weight(G, u, v, weight='weight'):
...     w = 0
...     for nbr in set(G[u]) & set(G[v]):
...         w += G.edge[u][nbr].get(weight, 1) + G.edge[v][nbr].get(weight, 1)
...     return w
...
>>> # A complete bipartite graph with 4 nodes and 4 edges
>>> B = nx.complete_bipartite_graph(2,2)
>>> # Add some arbitrary weight to the edges
>>> for i, (u,v) in enumerate(B.edges()):
...     B.edge[u][v]['weight'] = i + 1
...
>>> for edge in B.edges(data=True):
...     print(edge)
...
(0, 2, {'weight': 1})
(0, 3, {'weight': 2})
(1, 2, {'weight': 3})
(1, 3, {'weight': 4})
>>> # Without specifying a function, the weight is equal to # shared partners
>>> G = bipartite.generic_weighted_projected_graph(B, [0, 1])
>>> print(G.edges(data=True))
[(0, 1, {'weight': 2})]
>>> # To specify a custom weight function use the weight_function parameter
>>> G = bipartite.generic_weighted_projected_graph(B, [0, 1], weight_function=jaccard)
>>> print(G.edges(data=True))
[(0, 1, {'weight': 1.0})]
>>> G = bipartite.generic_weighted_projected_graph(B, [0, 1], weight_function=my_weight)
>>> print(G.edges(data=True))
[(0, 1, {'weight': 10})]
```

No attempt is made to verify that the input graph B is bipartite. The graph and node properties are (shallow) copied to the projected graph.

See also:

`is_bipartite()`, `is_bipartite_node_set()`, `sets()`, `weighted_projected_graph()`, `collaboration_weighted_projected_graph()`, `overlap_weighted_projected_graph()`, `projected_graph()`

4.3.5 Spectral

Spectral bipartivity measure.

`spectral_bipartivity(G[, nodes, weight])` Returns the spectral bipartivity.

spectral_bipartivity

spectral_bipartivity (*G*, *nodes=None*, *weight='weight'*)

Returns the spectral bipartivity.

Parameters

- **G** (*NetworkX graph*) –
- **nodes** (*list or container optional(default is all nodes)*) – Nodes to return value of spectral bipartivity contribution.
- **weight** (*string or None optional (default = 'weight')*) – Edge data key to use for edge weights. If None, weights set to 1.

Returns sb – A single number if the keyword nodes is not specified, or a dictionary keyed by node with the spectral bipartivity contribution of that node as the value.

Return type float or dict

Examples

```
>>> from networkx.algorithms import bipartite
>>> G = nx.path_graph(4)
>>> bipartite.spectral_bipartivity(G)
1.0
```

Notes

This implementation uses Numpy (dense) matrices which are not efficient for storing large sparse graphs.

See also:

`color()`

References

4.3.6 Clustering

<code>clustering(G[, nodes, mode])</code>	Compute a bipartite clustering coefficient for nodes.
<code>average_clustering(G[, nodes, mode])</code>	Compute the average bipartite clustering coefficient.
<code>latapy_clustering(G[, nodes, mode])</code>	Compute a bipartite clustering coefficient for nodes.
<code>robins_alexander_clustering(G)</code>	Compute the bipartite clustering of G.

clustering

clustering (*G*, *nodes=None*, *mode='dot'*)

Compute a bipartite clustering coefficient for nodes.

The bipartite clustering coefficient is a measure of local density of connections defined as ¹²:

$$c_u = \frac{\sum_{v \in N(N(u))} c_{uv}}{|N(N(u))|}$$

where $N(N(u))$ are the second order neighbors of u in G excluding u , and c_{uv} is the pairwise clustering coefficient between nodes u and v .

The mode selects the function for c_{uv} which can be:

dot:

$$c_{uv} = \frac{|N(u) \cap N(v)|}{|N(u) \cup N(v)|}$$

min:

$$c_{uv} = \frac{|N(u) \cap N(v)|}{\min(|N(u)|, |N(v)|)}$$

max:

$$c_{uv} = \frac{|N(u) \cap N(v)|}{\max(|N(u)|, |N(v)|)}$$

Parameters

- **G** (*graph*) – A bipartite graph
- **nodes** (*list or iterable (optional)*) – Compute bipartite clustering for these nodes. The default is all nodes in G.
- **mode** (*string*) – The pairwise bipartite clustering method to be used in the computation. It must be “dot”, “max”, or “min”.

Returns **clustering** – A dictionary keyed by node with the clustering coefficient value.

Return type dictionary

Examples

```
>>> from networkx.algorithms import bipartite
>>> G = nx.path_graph(4) # path graphs are bipartite
>>> c = bipartite.clustering(G)
>>> c[0]
0.5
>>> c = bipartite.clustering(G, mode='min')
>>> c[0]
1.0
```

See also:

[`robins_alexander_clustering\(\)`](#), [`square_clustering\(\)`](#), [`average_clustering\(\)`](#)

¹² Latapy, Matthieu, Clémence Magnien, and Nathalie Del Vecchio (2008). Basic notions for the analysis of large two-mode networks. Social Networks 30(1), 31–48.

References

average_clustering

average_clustering (*G*, *nodes=None*, *mode='dot'*)

Compute the average bipartite clustering coefficient.

A clustering coefficient for the whole graph is the average,

$$C = \frac{1}{n} \sum_{v \in G} c_v,$$

where n is the number of nodes in G .

Similar measures for the two bipartite sets can be defined ¹³

$$C_X = \frac{1}{|X|} \sum_{v \in X} c_v,$$

where X is a bipartite set of G .

Parameters

- **G** (*graph*) – a bipartite graph
- **nodes** (*list or iterable, optional*) – A container of nodes to use in computing the average. The nodes should be either the entire graph (the default) or one of the bipartite sets.
- **mode** (*string*) – The pairwise bipartite clustering method. It must be “dot”, “max”, or “min”

Returns clustering – The average bipartite clustering for the given set of nodes or the entire graph if no nodes are specified.

Return type `float`

Examples

```
>>> from networkx.algorithms import bipartite
>>> G=nx.star_graph(3) # star graphs are bipartite
>>> bipartite.average_clustering(G)
0.75
>>> X,Y=bipartite.sets(G)
>>> bipartite.average_clustering(G,X)
0.0
>>> bipartite.average_clustering(G,Y)
1.0
```

See also:

`clustering()`

Notes

The container of nodes passed to this function must contain all of the nodes in one of the bipartite sets (“top” or “bottom”) in order to compute the correct average bipartite clustering coefficients.

¹³ Latapy, Matthieu, Clémence Magnien, and Nathalie Del Vecchio (2008). Basic notions for the analysis of large two-mode networks. *Social Networks* 30(1), 31–48.

References

latapy_clustering

latapy_clustering (*G*, *nodes=None*, *mode='dot'*)

Compute a bipartite clustering coefficient for nodes.

The bipartite clustering coefficient is a measure of local density of connections defined as ¹⁴:

$$c_u = \frac{\sum_{v \in N(N(u))} c_{uv}}{|N(N(u))|}$$

where $N(N(u))$ are the second order neighbors of u in G excluding u , and c_{uv} is the pairwise clustering coefficient between nodes u and v .

The mode selects the function for c_{uv} which can be:

dot:

$$c_{uv} = \frac{|N(u) \cap N(v)|}{|N(u) \cup N(v)|}$$

min:

$$c_{uv} = \frac{|N(u) \cap N(v)|}{\min(|N(u)|, |N(v)|)}$$

max:

$$c_{uv} = \frac{|N(u) \cap N(v)|}{\max(|N(u)|, |N(v)|)}$$

Parameters

- **G** (*graph*) – A bipartite graph
- **nodes** (*list or iterable (optional)*) – Compute bipartite clustering for these nodes. The default is all nodes in G.
- **mode** (*string*) – The pairwise bipartite clustering method to be used in the computation. It must be “dot”, “max”, or “min”.

Returns **clustering** – A dictionary keyed by node with the clustering coefficient value.

Return type dictionary

Examples

```
>>> from networkx.algorithms import bipartite
>>> G = nx.path_graph(4) # path graphs are bipartite
>>> c = bipartite.clustering(G)
>>> c[0]
0.5
>>> c = bipartite.clustering(G, mode='min')
>>> c[0]
1.0
```

See also:

[`robins_alexander_clustering\(\)`](#), [`square_clustering\(\)`](#), [`average_clustering\(\)`](#)

¹⁴ Latapy, Matthieu, Clémence Magnien, and Nathalie Del Vecchio (2008). Basic notions for the analysis of large two-mode networks. Social Networks 30(1), 31–48.

References

robins_alexander_clustering

robins_alexander_clustering(*G*)

Compute the bipartite clustering of *G*.

Robins and Alexander¹⁵ defined bipartite clustering coefficient as four times the number of four cycles C_4 divided by the number of three paths L_3 in a bipartite graph:

$$CC_4 = \frac{4 * C_4}{L_3}$$

Parameters *G* (*graph*) – a bipartite graph

Returns *clustering* – The Robins and Alexander bipartite clustering for the input graph.

Return type *float*

Examples

```
>>> from networkx.algorithms import bipartite
>>> G = nx.davis_southern_women_graph()
>>> print(round(bipartite.robins_alexander_clustering(G), 3))
0.468
```

See also:

latapy_clustering(), *square_clustering()*

References

4.3.7 Redundancy

Node redundancy for bipartite graphs.

node_redundancy(*G*[, *nodes*]) Computes the node redundancy coefficients for the nodes in the bipartite graph *G*.

node_redundancy

node_redundancy(*G*, *nodes=None*)

Computes the node redundancy coefficients for the nodes in the bipartite graph *G*.

The redundancy coefficient of a node *v* is the fraction of pairs of neighbors of *v* that are both linked to other nodes. In a one-mode projection these nodes would be linked together even if *v* were not there.

More formally, for any vertex *v*, the *redundancy coefficient* of ‘*v*’ is defined by

$$rc(v) = \frac{|\{\{u, w\} \subseteq N(v), \exists v' \neq v, (v', u) \in E \text{ and } (v', w) \in E\}|}{\frac{|N(v)|(|N(v)|-1)}{2}},$$

where $N(v)$ is the set of neighbors of *v* in *G*.

¹⁵ Robins, G. and M. Alexander (2004). Small worlds among interlocking directors: Network structure and distance in bipartite graphs. Computational & Mathematical Organization Theory 10(1), 69–94.

Parameters

- **G** (*graph*) – A bipartite graph
- **nodes** (*list or iterable (optional)*) – Compute redundancy for these nodes. The default is all nodes in G.

Returns **redundancy** – A dictionary keyed by node with the node redundancy value.

Return type dictionary

Examples

Compute the redundancy coefficient of each node in a graph:

```
>>> import networkx as nx
>>> from networkx.algorithms import bipartite
>>> G = nx.cycle_graph(4)
>>> rc = bipartite.node_redundancy(G)
>>> rc[0]
1.0
```

Compute the average redundancy for the graph:

```
>>> import networkx as nx
>>> from networkx.algorithms import bipartite
>>> G = nx.cycle_graph(4)
>>> rc = bipartite.node_redundancy(G)
>>> sum(rc.values()) / len(G)
1.0
```

Compute the average redundancy for a set of nodes:

```
>>> import networkx as nx
>>> from networkx.algorithms import bipartite
>>> G = nx.cycle_graph(4)
>>> rc = bipartite.node_redundancy(G)
>>> nodes = [0, 2]
>>> sum(rc[n] for n in nodes) / len(nodes)
1.0
```

Raises `NetworkXError` – If any of the nodes in the graph (or in `nodes`, if specified) has (out-)degree less than two (which would result in division by zero, according to the definition of the redundancy coefficient).

References**4.3.8 Centrality**

<code>closeness_centrality(G, nodes[, normalized])</code>	Compute the closeness centrality for nodes in a bipartite network.
<code>degree_centrality(G, nodes)</code>	Compute the degree centrality for nodes in a bipartite network.
<code>betweenness_centrality(G, nodes)</code>	Compute betweenness centrality for nodes in a bipartite network.

closeness_centrality

closeness_centrality (*G*, *nodes*, *normalized=True*)

Compute the closeness centrality for nodes in a bipartite network.

The closeness of a node is the distance to all other nodes in the graph or in the case that the graph is not connected to all other nodes in the connected component containing that node.

Parameters

- **G** (*graph*) – A bipartite network
- **nodes** (*list or container*) – Container with all nodes in one bipartite node set.
- **normalized** (*bool, optional*) – If True (default) normalize by connected component size.

Returns **closeness** – Dictionary keyed by node with bipartite closeness centrality as the value.

Return type dictionary

See also:

`betweenness_centrality()`, `degree_centrality()`, `sets()`, `is_bipartite()`

Notes

The nodes input parameter must contain all nodes in one bipartite node set, but the dictionary returned contains all nodes from both node sets.

Closeness centrality is normalized by the minimum distance possible. In the bipartite case the minimum distance for a node in one bipartite node set is 1 from all nodes in the other node set and 2 from all other nodes in its own set¹⁶. Thus the closeness centrality for node v in the two bipartite sets U with n nodes and V with m nodes is

$$c_v = \frac{m + 2(n - 1)}{d}, \text{ for } v \in U,$$
$$c_v = \frac{n + 2(m - 1)}{d}, \text{ for } v \in V,$$

where d is the sum of the distances from v to all other nodes.

Higher values of closeness indicate higher centrality.

As in the unipartite case, setting `normalized=True` causes the values to be normalized further to $n-1 / \text{size}(G)-1$ where n is the number of nodes in the connected part of graph containing the node. If the graph is not completely connected, this algorithm computes the closeness centrality for each connected part separately.

References

degree_centrality

degree_centrality (*G*, *nodes*)

Compute the degree centrality for nodes in a bipartite network.

The degree centrality for a node v is the fraction of nodes connected to it.

Parameters

- **G** (*graph*) – A bipartite network

¹⁶ Borgatti, S.P. and Halgin, D. In press. "Analyzing Affiliation Networks". In Carrington, P. and Scott, J. (eds) The Sage Handbook of Social Network Analysis. Sage Publications. <http://www.steveborgatti.com/papers/bhaffiliations.pdf>

- **nodes** (*list or container*) – Container with all nodes in one bipartite node set.

Returns **centrality** – Dictionary keyed by node with bipartite degree centrality as the value.

Return type dictionary

See also:

`betweenness_centrality()`, `closeness_centrality()`, `sets()`, `is_bipartite()`

Notes

The nodes input parameter must contain all nodes in one bipartite node set, but the dictionary returned contains all nodes from both bipartite node sets.

For unipartite networks, the degree centrality values are normalized by dividing by the maximum possible degree (which is $n - 1$ where n is the number of nodes in G).

In the bipartite case, the maximum possible degree of a node in a bipartite node set is the number of nodes in the opposite node set¹⁷. The degree centrality for a node v in the bipartite sets U with n nodes and V with m nodes is

$$d_v = \frac{\deg(v)}{m}, \text{ for } v \in U,$$

$$d_v = \frac{\deg(v)}{n}, \text{ for } v \in V,$$

where $\deg(v)$ is the degree of node v .

References

betweenness_centrality

betweenness_centrality (G , $nodes$)

Compute betweenness centrality for nodes in a bipartite network.

Betweenness centrality of a node v is the sum of the fraction of all-pairs shortest paths that pass through v .

Values of betweenness are normalized by the maximum possible value which for bipartite graphs is limited by the relative size of the two node sets¹⁸.

Let n be the number of nodes in the node set U and m be the number of nodes in the node set V , then nodes in U are normalized by dividing by

$$\frac{1}{2}[m^2(s+1)^2 + m(s+1)(2t-s-1) - t(2s-t+3)],$$

where

$$s = (n-1) \div m, t = (n-1) \bmod m,$$

and nodes in V are normalized by dividing by

$$\frac{1}{2}[n^2(p+1)^2 + n(p+1)(2r-p-1) - r(2p-r+3)],$$

¹⁷ Borgatti, S.P. and Halgin, D. In press. “Analyzing Affiliation Networks”. In Carrington, P. and Scott, J. (eds) The Sage Handbook of Social Network Analysis. Sage Publications. <http://www.steveborgatti.com/papers/bhaffiliations.pdf>

¹⁸ Borgatti, S.P. and Halgin, D. In press. “Analyzing Affiliation Networks”. In Carrington, P. and Scott, J. (eds) The Sage Handbook of Social Network Analysis. Sage Publications. <http://www.steveborgatti.com/papers/bhaffiliations.pdf>

where,

$$p = (m - 1) \div n, r = (m - 1) \bmod n.$$

Parameters

- **G** (*graph*) – A bipartite graph
- **nodes** (*list or container*) – Container with all nodes in one bipartite node set.

Returns **betweenness** – Dictionary keyed by node with bipartite betweenness centrality as the value.

Return type dictionary

See also:

`degree_centrality()`, `closeness_centrality()`, `sets()`, `is_bipartite()`

Notes

The nodes input parameter must contain all nodes in one bipartite node set, but the dictionary returned contains all nodes from both node sets.

References

4.3.9 Generators

Generators and functions for bipartite graphs.

<code>complete_bipartite_graph(n1, n2[, create_using])</code>	Return the complete bipartite graph K_{n_1, n_2} .
<code>configuration_model(aseq, bseq[, ...])</code>	Return a random bipartite graph from two given degree sequences.
<code>havel_hakimi_graph(aseq, bseq[, create_using])</code>	Return a bipartite graph from two given degree sequences using a Havel-Hakimi algorithm.
<code>reverse_havel_hakimi_graph(aseq, bseq[, ...])</code>	Return a bipartite graph from two given degree sequences using a reverse Havel-Hakimi algorithm.
<code>alternating_havel_hakimi_graph(aseq, bseq[, ...])</code>	Return a bipartite graph from two given degree sequences using an alternating Havel-Hakimi algorithm.
<code>preferential_attachment_graph(aseq, p[, ...])</code>	Create a bipartite graph with a preferential attachment model from a given degree sequence.
<code>random_graph(n, m, p[, seed, directed])</code>	Return a bipartite random graph.
<code>gnmk_random_graph(n, m, k[, seed, directed])</code>	Return a random bipartite graph $G_{\{n, m, k\}}$.

complete_bipartite_graph

complete_bipartite_graph (*n1, n2, create_using=None*)

Return the complete bipartite graph K_{n_1, n_2} .

Composed of two partitions with n_1 nodes in the first and n_2 nodes in the second. Each node in the first is connected to each node in the second.

Parameters

- **n1** (*integer*) – Number of nodes for node set A.
- **n2** (*integer*) – Number of nodes for node set B.
- **create_using** (*NetworkX graph instance, optional*) – Return graph of this type.

Notes

Node labels are the integers 0 to $n_1 + n_2 - 1$.

The nodes are assigned the attribute 'bipartite' with the value 0 or 1 to indicate which bipartite set the node belongs to.

configuration_model

configuration_model (*aseq*, *bseq*, *create_using=None*, *seed=None*)

Return a random bipartite graph from two given degree sequences.

Parameters

- **aseq** (*list*) – Degree sequence for node set A.
- **bseq** (*list*) – Degree sequence for node set B.
- **create_using** (*NetworkX graph instance, optional*) – Return graph of this type.
- **seed** (*integer, optional*) – Seed for random number generator.
- **from the set A are connected to nodes in the set B by** (*Nodes*) –
- **randomly from the possible free stubs, one in A and** (*choosing*) –
- **in B.** (*one*) –

Notes

The sum of the two sequences must be equal: $\text{sum}(\text{aseq}) = \text{sum}(\text{bseq})$ If no graph type is specified use MultiGraph with parallel edges. If you want a graph with no parallel edges use `create_using=Graph()` but then the resulting degree sequences might not be exact.

The nodes are assigned the attribute 'bipartite' with the value 0 or 1 to indicate which bipartite set the node belongs to.

This function is not imported in the main namespace. To use it you have to explicitly import the bipartite package.

havel_hakimi_graph

havel_hakimi_graph (*aseq*, *bseq*, *create_using=None*)

Return a bipartite graph from two given degree sequences using a Havel-Hakimi style construction.

Nodes from the set A are connected to nodes in the set B by connecting the highest degree nodes in set A to the highest degree nodes in set B until all stubs are connected.

Parameters

- **aseq** (*list*) – Degree sequence for node set A.
- **bseq** (*list*) – Degree sequence for node set B.
- **create_using** (*NetworkX graph instance, optional*) – Return graph of this type.

Notes

This function is not imported in the main namespace. To use it you have to explicitly import the bipartite package.

The sum of the two sequences must be equal: $\text{sum}(\text{aseq}) = \text{sum}(\text{bseq})$ If no graph type is specified use `MultiGraph` with parallel edges. If you want a graph with no parallel edges use `create_using=Graph()` but then the resulting degree sequences might not be exact.

The nodes are assigned the attribute 'bipartite' with the value 0 or 1 to indicate which bipartite set the node belongs to.

`reverse_havel_hakimi_graph`

`reverse_havel_hakimi_graph` (*aseq, bseq, create_using=None*)

Return a bipartite graph from two given degree sequences using a Havel-Hakimi style construction.

Nodes from set A are connected to nodes in the set B by connecting the highest degree nodes in set A to the lowest degree nodes in set B until all stubs are connected.

Parameters

- **`aseq`** (*list*) – Degree sequence for node set A.
- **`bseq`** (*list*) – Degree sequence for node set B.
- **`create_using`** (*NetworkX graph instance, optional*) – Return graph of this type.

Notes

This function is not imported in the main namespace. To use it you have to explicitly import the bipartite package.

The sum of the two sequences must be equal: $\text{sum}(\text{aseq}) = \text{sum}(\text{bseq})$ If no graph type is specified use `MultiGraph` with parallel edges. If you want a graph with no parallel edges use `create_using=Graph()` but then the resulting degree sequences might not be exact.

The nodes are assigned the attribute 'bipartite' with the value 0 or 1 to indicate which bipartite set the node belongs to.

`alternating_havel_hakimi_graph`

`alternating_havel_hakimi_graph` (*aseq, bseq, create_using=None*)

Return a bipartite graph from two given degree sequences using an alternating Havel-Hakimi style construction.

Nodes from the set A are connected to nodes in the set B by connecting the highest degree nodes in set A to alternatively the highest and the lowest degree nodes in set B until all stubs are connected.

Parameters

- **`aseq`** (*list*) – Degree sequence for node set A.
- **`bseq`** (*list*) – Degree sequence for node set B.
- **`create_using`** (*NetworkX graph instance, optional*) – Return graph of this type.

Notes

This function is not imported in the main namespace. To use it you have to explicitly import the bipartite package.

The sum of the two sequences must be equal: $\text{sum}(\text{aseq}) = \text{sum}(\text{bseq})$ If no graph type is specified use `MultiGraph` with parallel edges. If you want a graph with no parallel edges use `create_using=Graph()` but then the resulting degree sequences might not be exact.

The nodes are assigned the attribute 'bipartite' with the value 0 or 1 to indicate which bipartite set the node belongs to.

preferential_attachment_graph

preferential_attachment_graph (*aseq*, *p*, *create_using=None*, *seed=None*)

Create a bipartite graph with a preferential attachment model from a given single degree sequence.

Parameters

- **aseq** (*list*) – Degree sequence for node set A.
- **p** (*float*) – Probability that a new bottom node is added.
- **create_using** (*NetworkX graph instance, optional*) – Return graph of this type.
- **seed** (*integer, optional*) – Seed for random number generator.

References

Notes

This function is not imported in the main namespace. To use it you have to explicitly import the bipartite package.

random_graph

random_graph (*n*, *m*, *p*, *seed=None*, *directed=False*)

Return a bipartite random graph.

This is a bipartite version of the binomial (Erdős-Rényi) graph.

Parameters

- **n** (*int*) – The number of nodes in the first bipartite set.
- **m** (*int*) – The number of nodes in the second bipartite set.
- **p** (*float*) – Probability for edge creation.
- **seed** (*int, optional*) – Seed for random number generator (default=None).
- **directed** (*bool, optional (default=False)*) – If True return a directed graph

Notes

This function is not imported in the main namespace. To use it you have to explicitly import the bipartite package.

The bipartite random graph algorithm chooses each of the $n*m$ (undirected) or $2*nm$ (directed) possible edges with probability p .

This algorithm is $O(n+m)$ where m is the expected number of edges.

The nodes are assigned the attribute 'bipartite' with the value 0 or 1 to indicate which bipartite set the node belongs to.

See also:

`gnp_random_graph()`, `configuration_model()`

References

gnmk_random_graph

gnmk_random_graph (*n*, *m*, *k*, *seed=None*, *directed=False*)

Return a random bipartite graph $G_{\{n,m,k\}}$.

Produces a bipartite graph chosen randomly out of the set of all graphs with n top nodes, m bottom nodes, and k edges.

Parameters

- **n** (*int*) – The number of nodes in the first bipartite set.
- **m** (*int*) – The number of nodes in the second bipartite set.
- **k** (*int*) – The number of edges
- **seed** (*int, optional*) – Seed for random number generator (default=None).
- **directed** (*bool, optional (default=False)*) – If True return a directed graph

Examples

```
from networkx.algorithms import bipartite
G = bipartite.gnmk_random_graph(10,20,50)
```

See also:

`gnm_random_graph()`

Notes

This function is not imported in the main namespace. To use it you have to explicitly import the bipartite package.

If $k > m * n$ then a complete bipartite graph is returned.

This graph is a bipartite version of the G_{nm} random graph model.

4.4 Blockmodeling

Functions for creating network blockmodels from node partitions.

Created by Drew Conway <drew.conway@nyu.edu> Copyright (c) 2010. All rights reserved.

`blockmodel(G, partitions[, multigraph])` Returns a reduced graph constructed using the generalized block modeling technique.

4.4.1 blockmodel

blockmodel (*G, partitions, multigraph=False*)

Returns a reduced graph constructed using the generalized block modeling technique.

The blockmodel technique collapses nodes into blocks based on a given partitioning of the node set. Each partition of nodes (block) is represented as a single node in the reduced graph.

Edges between nodes in the block graph are added according to the edges in the original graph. If the parameter `multigraph` is `False` (the default) a single edge is added with a weight equal to the sum of the edge weights between nodes in the original graph. The default is a weight of 1 if weights are not specified. If the parameter `multigraph` is `True` then multiple edges are added each with the edge data from the original graph.

Parameters

- **G** (*graph*) – A networkx Graph or DiGraph
- **partitions** (*list of lists, or list of sets*) – The partition of the nodes. Must be non-overlapping.
- **multigraph** (*bool, optional*) – If `True` return a MultiGraph with the edge data of the original graph applied to each corresponding edge in the new graph. If `False` return a Graph with the sum of the edge weights, or a count of the edges if the original graph is unweighted.

Returns blockmodel

Return type a Networkx graph object

Examples

```
>>> G=nx.path_graph(6)
>>> partition=[[0,1],[2,3],[4,5]]
>>> M=nx.blockmodel(G,partition)
```

References

4.5 Boundary

Routines to find the boundary of a set of nodes.

Edge boundaries are edges that have only one end in the set of nodes.

Node boundaries are nodes outside the set of nodes that have an edge to a node in the set.

<code>edge_boundary(G, nbunch1[, nbunch2])</code>	Return the edge boundary.
<code>node_boundary(G, nbunch1[, nbunch2])</code>	Return the node boundary.

4.5.1 edge_boundary

edge_boundary (*G*, *nbunch1*, *nbunch2=None*)

Return the edge boundary.

Edge boundaries are edges that have only one end in the given set of nodes.

Parameters

- **G** (*graph*) – A networkx graph
- **nbunch1** (*list, container*) – Interior node set
- **nbunch2** (*list, container*) – Exterior node set. If None then it is set to all of the nodes in G not in nbunch1.

Returns **elist** – List of edges

Return type `list`

Notes

Nodes in nbunch1 and nbunch2 that are not in G are ignored.

nbunch1 and nbunch2 are usually meant to be disjoint, but in the interest of speed and generality, that is not required here.

4.5.2 node_boundary

node_boundary (*G*, *nbunch1*, *nbunch2=None*)

Return the node boundary.

The node boundary is all nodes in the edge boundary of a given set of nodes that are in the set.

Parameters

- **G** (*graph*) – A networkx graph
- **nbunch1** (*list, container*) – Interior node set
- **nbunch2** (*list, container*) – Exterior node set. If None then it is set to all of the nodes in G not in nbunch1.

Returns **nlist** – List of nodes.

Return type `list`

Notes

Nodes in nbunch1 and nbunch2 that are not in G are ignored.

nbunch1 and nbunch2 are usually meant to be disjoint, but in the interest of speed and generality, that is not required here.

4.6 Centrality

4.6.1 Degree

4.6.2 Closeness

4.6.3 Betweenness

4.6.4 Current Flow Closeness

4.6.5 Current-Flow Betweenness

4.6.6 Eigenvector

4.6.7 Communicability

4.6.8 Load

4.6.9 Dispersion

4.7 Chordal

Algorithms for chordal graphs.

A graph is chordal if every cycle of length at least 4 has a chord (an edge joining two nodes not adjacent in the cycle).
http://en.wikipedia.org/wiki/Chordal_graph

<code>is_chordal(G)</code>	Checks whether G is a chordal graph.
<code>chordal_graph_cliques(G)</code>	Returns the set of maximal cliques of a chordal graph.
<code>chordal_graph_treewidth(G)</code>	Returns the treewidth of the chordal graph G.
<code>find_induced_nodes(G, s, t[, treewidth_bound])</code>	Returns the set of induced nodes in the path from s to t.

4.7.1 is_chordal

is_chordal (*G*)

Checks whether *G* is a chordal graph.

A graph is chordal if every cycle of length at least 4 has a chord (an edge joining two nodes not adjacent in the cycle).

Parameters *G* (*graph*) – A NetworkX graph.

Returns **chordal** – True if *G* is a chordal graph and False otherwise.

Return type **bool**

Raises **NetworkXError** – The algorithm does not support DiGraph, MultiGraph and MultiDiGraph. If the input graph is an instance of one of these classes, a NetworkXError is raised.

Examples

```
>>> import networkx as nx
>>> e=[ (1,2), (1,3), (2,3), (2,4), (3,4), (3,5), (3,6), (4,5), (4,6), (5,6) ]
>>> G=nx.Graph(e)
>>> nx.is_chordal(G)
True
```

Notes

The routine tries to go through every node following maximum cardinality search. It returns False when it finds that the separator for any node is not a clique. Based on the algorithms in ¹⁹.

References

4.7.2 chordal_graph_cliques

chordal_graph_cliques (*G*)

Returns the set of maximal cliques of a chordal graph.

The algorithm breaks the graph in connected components and performs a maximum cardinality search in each component to get the cliques.

Parameters *G* (*graph*) – A NetworkX graph

Returns **cliques**

Return type A set containing the maximal cliques in *G*.

Raises **NetworkXError** – The algorithm does not support DiGraph, MultiGraph and MultiDiGraph. If the input graph is an instance of one of these classes, a NetworkXError is raised. The algorithm can only be applied to chordal graphs. If the input graph is found to be non-chordal, a NetworkXError is raised.

¹⁹ R. E. Tarjan and M. Yannakakis, Simple linear-time algorithms to test chordality of graphs, test acyclicity of hypergraphs, and selectively reduce acyclic hypergraphs, SIAM J. Comput., 13 (1984), pp. 566–579.

Examples

```
>>> import networkx as nx
>>> e= [(1,2), (1,3), (2,3), (2,4), (3,4), (3,5), (3,6), (4,5), (4,6), (5,6), (7,8)]
>>> G = nx.Graph(e)
>>> G.add_node(9)
>>> setlist = nx.chordal_graph_cliques(G)
```

4.7.3 chordal_graph_treewidth

chordal_graph_treewidth(*G*)

Returns the treewidth of the chordal graph *G*.

Parameters *G* (*graph*) – A NetworkX graph

Returns **treewidth** – The size of the largest clique in the graph minus one.

Return type **int**

Raises **NetworkXError** – The algorithm does not support DiGraph, MultiGraph and MultiDiGraph. If the input graph is an instance of one of these classes, a NetworkXError is raised. The algorithm can only be applied to chordal graphs. If the input graph is found to be non-chordal, a NetworkXError is raised.

Examples

```
>>> import networkx as nx
>>> e = [(1,2), (1,3), (2,3), (2,4), (3,4), (3,5), (3,6), (4,5), (4,6), (5,6), (7,8)]
>>> G = nx.Graph(e)
>>> G.add_node(9)
>>> nx.chordal_graph_treewidth(G)
3
```

References

4.7.4 find_induced_nodes

find_induced_nodes(*G*, *s*, *t*, *treewidth_bound*=9223372036854775807)

Returns the set of induced nodes in the path from *s* to *t*.

Parameters

- **G** (*graph*) – A chordal NetworkX graph
- **s** (*node*) – Source node to look for induced nodes
- **t** (*node*) – Destination node to look for induced nodes
- **treewidth_bound** (*float*) – Maximum treewidth acceptable for the graph *H*. The search for induced nodes will end as soon as the *treewidth_bound* is exceeded.

Returns **I** – The set of induced nodes in the path from *s* to *t* in *G*

Return type Set of nodes

Raises `NetworkXError` – The algorithm does not support `DiGraph`, `MultiGraph` and `MultiDiGraph`. If the input graph is an instance of one of these classes, a `NetworkXError` is raised. The algorithm can only be applied to chordal graphs. If the input graph is found to be non-chordal, a `NetworkXError` is raised.

Examples

```
>>> import networkx as nx
>>> G=nx.Graph()
>>> G = nx.generators.classic.path_graph(10)
>>> I = nx.find_induced_nodes(G, 1, 9, 2)
>>> list(I)
[1, 2, 3, 4, 5, 6, 7, 8, 9]
```

Notes

`G` must be a chordal graph and `(s,t)` an edge that is not in `G`.

If a `treewidth_bound` is provided, the search for induced nodes will end as soon as the `treewidth_bound` is exceeded.

The algorithm is inspired by Algorithm 4 in ²⁰. A formal definition of induced node can also be found on that reference.

References

4.8 Clique

4.8.1 Cliques

Find and manipulate cliques of graphs.

Note that finding the largest clique of a graph has been shown to be an NP-complete problem; the algorithms here could take a long time to run.

http://en.wikipedia.org/wiki/Clique_problem

<code>enumerate_all_cliques(G)</code>	Returns all cliques in an undirected graph.
<code>find_cliques(G)</code>	Search for all maximal cliques in a graph.
<code>make_max_clique_graph(G[, create_using, name])</code>	Create the maximal clique graph of a graph.
<code>make_clique_bipartite(G[, fpos, ...])</code>	Create a bipartite clique graph from a graph <code>G</code> .
<code>graph_clique_number(G[, cliques])</code>	Return the clique number (size of the largest clique) for <code>G</code> .
<code>graph_number_of_cliques(G[, cliques])</code>	Returns the number of maximal cliques in <code>G</code> .
<code>node_clique_number(G[, nodes, cliques])</code>	Returns the size of the largest maximal clique containing each given node.
<code>number_of_cliques(G[, nodes, cliques])</code>	Returns the number of maximal cliques for each node.
<code>cliques_containing_node(G[, nodes, cliques])</code>	Returns a list of cliques containing the given node.

²⁰ Learning Bounded Treewidth Bayesian Networks. Gal Elidan, Stephen Gould; JMLR, 9(Dec):2699–2731, 2008.
<http://jmlr.csail.mit.edu/papers/volume9/elidan08a/elidan08a.pdf>

4.8.2 enumerate_all_cliques

enumerate_all_cliques (*G*)

Returns all cliques in an undirected graph.

This method returns cliques of size (cardinality) $k = 1, 2, 3, \dots, \text{maxDegree} - 1$.

Where `maxDegree` is the maximal degree of any node in the graph.

Parameters *G* (*undirected graph*) –

Returns generator of lists

Return type generator of list for each clique.

Notes

To obtain a list of all cliques, use `list(enumerate_all_cliques(G))`.

Based on the algorithm published by Zhang et al. (2005)²¹ and adapted to output all cliques discovered.

This algorithm is not applicable on directed graphs.

This algorithm ignores self-loops and parallel edges as clique is not conventionally defined with such edges.

There are often many cliques in graphs. This algorithm however, hopefully, does not run out of memory since it only keeps candidate sublists in memory and continuously removes exhausted sublists.

References

4.8.3 find_cliques

find_cliques (*G*)

Search for all maximal cliques in a graph.

Maximal cliques are the largest complete subgraph containing a given node. The largest maximal clique is sometimes called the maximum clique.

Returns generator of lists

Return type genetor of member list for each maximal clique

See also:

`find_cliques_recursive()`, `A()`

Notes

To obtain a list of cliques, use `list(find_cliques(G))`.

Based on the algorithm published by Bron & Kerbosch (1973)²² as adapted by Tomita, Tanaka and Takahashi

²¹ Yun Zhang, Abu-Khzam, F.N., Baldwin, N.E., Chesler, E.J., Langston, M.A., Samatova, N.F., Genome-Scale Computational Approaches to Memory-Intensive Applications in Systems Biology. Supercomputing, 2005. Proceedings of the ACM/IEEE SC 2005 Conference, pp. 12, 12-18 Nov. 2005. doi: 10.1109/SC.2005.29. <http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1559964&isnumber=33129>

²² Bron, C. and Kerbosch, J. 1973. Algorithm 457: finding all cliques of an undirected graph. Commun. ACM 16, 9 (Sep. 1973), 575-577. <http://portal.acm.org/citation.cfm?doid=362342.362367>

(2006)²³ and discussed in Cazals and Karande (2008)²⁴. The method essentially unrolls the recursion used in the references to avoid issues of recursion stack depth.

This algorithm is not suitable for directed graphs.

This algorithm ignores self-loops and parallel edges as clique is not conventionally defined with such edges.

There are often many cliques in graphs. This algorithm can run out of memory for large graphs.

References

4.8.4 `make_max_clique_graph`

`make_max_clique_graph` (*G*, *create_using=None*, *name=None*)

Create the maximal clique graph of a graph.

Finds the maximal cliques and treats these as nodes. The nodes are connected if they have common members in the original graph. Theory has done a lot with clique graphs, but I haven't seen much on maximal clique graphs.

Notes

This should be the same as `make_clique_bipartite` followed by `project_up`, but it saves all the intermediate steps.

4.8.5 `make_clique_bipartite`

`make_clique_bipartite` (*G*, *fpos=None*, *create_using=None*, *name=None*)

Create a bipartite clique graph from a graph *G*.

Nodes of *G* are retained as the “bottom nodes” of *B* and cliques of *G* become “top nodes” of *B*. Edges are present if a bottom node belongs to the clique represented by the top node.

Returns a Graph with additional attribute dict *B.node_type* which is keyed by nodes to “Bottom” or “Top” appropriately.

if *fpos* is not *None*, a second additional attribute dict *B.pos* is created to hold the position tuple of each node for viewing the bipartite graph.

4.8.6 `graph_clique_number`

`graph_clique_number` (*G*, *cliques=None*)

Return the clique number (size of the largest clique) for *G*.

An optional list of cliques can be input if already computed.

²³ Etsuji Tomita, Akira Tanaka, Haruhisa Takahashi, The worst-case time complexity for generating all maximal cliques and computational experiments, Theoretical Computer Science, Volume 363, Issue 1, Computing and Combinatorics, 10th Annual International Conference on Computing and Combinatorics (COCOON 2004), 25 October 2006, Pages 28-42 <http://dx.doi.org/10.1016/j.tcs.2006.06.015>

²⁴ F. Cazals, C. Karande, A note on the problem of reporting maximal cliques, Theoretical Computer Science, Volume 407, Issues 1-3, 6 November 2008, Pages 564-568, <http://dx.doi.org/10.1016/j.tcs.2008.05.010>

4.8.7 graph_number_of_cliques

graph_number_of_cliques (*G*, *cliques=None*)

Returns the number of maximal cliques in *G*.

An optional list of cliques can be input if already computed.

4.8.8 node_clique_number

node_clique_number (*G*, *nodes=None*, *cliques=None*)

Returns the size of the largest maximal clique containing each given node.

Returns a single or list depending on input nodes. Optional list of cliques can be input if already computed.

4.8.9 number_of_cliques

number_of_cliques (*G*, *nodes=None*, *cliques=None*)

Returns the number of maximal cliques for each node.

Returns a single or list depending on input nodes. Optional list of cliques can be input if already computed.

4.8.10 cliques_containing_node

cliques_containing_node (*G*, *nodes=None*, *cliques=None*)

Returns a list of cliques containing the given node.

Returns a single list or list of lists depending on input nodes. Optional list of cliques can be input if already computed.

4.9 Clustering

Algorithms to characterize the number of triangles in a graph.

<i>triangles</i> (<i>G</i> [, <i>nodes</i>])	Compute the number of triangles.
<i>transitivity</i> (<i>G</i>)	Compute graph transitivity, the fraction of all possible triangles present in <i>G</i> .
<i>clustering</i> (<i>G</i> [, <i>nodes</i> , <i>weight</i>])	Compute the clustering coefficient for nodes.
<i>average_clustering</i> (<i>G</i> [, <i>nodes</i> , <i>weight</i> , ...])	Compute the average clustering coefficient for the graph <i>G</i> .
<i>square_clustering</i> (<i>G</i> [, <i>nodes</i>])	Compute the squares clustering coefficient for nodes.

4.9.1 triangles

triangles (*G*, *nodes=None*)

Compute the number of triangles.

Finds the number of triangles that include a node as one vertex.

Parameters

- **G** (*graph*) – A networkx graph
- **nodes** (*container of nodes, optional (default= all nodes in G)*) – Compute triangles for nodes in this container.

Returns out – Number of triangles keyed by node label.

Return type dictionary

Examples

```
>>> G=nx.complete_graph(5)
>>> print(nx.triangles(G,0))
6
>>> print(nx.triangles(G))
{0: 6, 1: 6, 2: 6, 3: 6, 4: 6}
>>> print(list(nx.triangles(G, (0,1)).values()))
[6, 6]
```

Notes

When computing triangles for the entire graph each triangle is counted three times, once at each node. Self loops are ignored.

4.9.2 transitivity

transitivity(*G*)

Compute graph transitivity, the fraction of all possible triangles present in *G*.

Possible triangles are identified by the number of “triads” (two edges with a shared vertex).

The transitivity is

$$T = 3 \frac{\#triangles}{\#triads}.$$

Parameters *G* (*graph*) –

Returns out – Transitivity

Return type float

Examples

```
>>> G = nx.complete_graph(5)
>>> print(nx.transitivity(G))
1.0
```

4.9.3 clustering

clustering(*G*, *nodes=None*, *weight=None*)

Compute the clustering coefficient for nodes.

For unweighted graphs, the clustering of a node *u* is the fraction of possible triangles through that node that exist,

$$c_u = \frac{2T(u)}{\deg(u)(\deg(u) - 1)},$$

where $T(u)$ is the number of triangles through node u and $\deg(u)$ is the degree of u .

For weighted graphs, the clustering is defined as the geometric average of the subgraph edge weights ²⁵,

$$c_u = \frac{1}{\deg(u)(\deg(u) - 1)} \sum_{uv} (\hat{w}_{uv} \hat{w}_{uw} \hat{w}_{vw})^{1/3}.$$

The edge weights \hat{w}_{uv} are normalized by the maximum weight in the network $\hat{w}_{uv} = w_{uv} / \max(w)$.

The value of c_u is assigned to 0 if $\deg(u) < 2$.

Parameters

- **G** (*graph*) –
- **nodes** (*container of nodes, optional (default=all nodes in G)*) – Compute clustering for nodes in this container.
- **weight** (*string or None, optional (default=None)*) – The edge attribute that holds the numerical value used as a weight. If None, then each edge has weight 1.

Returns **out** – Clustering coefficient at specified nodes

Return type float, or dictionary

Examples

```
>>> G=nx.complete_graph(5)
>>> print(nx.clustering(G,0))
1.0
>>> print(nx.clustering(G))
{0: 1.0, 1: 1.0, 2: 1.0, 3: 1.0, 4: 1.0}
```

Notes

Self loops are ignored.

References

4.9.4 average_clustering

average_clustering (*G, nodes=None, weight=None, count_zeros=True*)

Compute the average clustering coefficient for the graph G .

The clustering coefficient for the graph is the average,

$$C = \frac{1}{n} \sum_{v \in G} c_v,$$

where n is the number of nodes in G .

Parameters

- **G** (*graph*) –

²⁵ Generalizations of the clustering coefficient to weighted complex networks by J. Saramäki, M. Kivelä, J.-P. Onnela, K. Kaski, and J. Kertész, Physical Review E, 75 027105 (2007). http://jponnola.com/web_documents/a9.pdf

- **nodes** (*container of nodes, optional (default=all nodes in G)*) – Compute average clustering for nodes in this container.
- **weight** (*string or None, optional (default=None)*) – The edge attribute that holds the numerical value used as a weight. If None, then each edge has weight 1.
- **count_zeros** (*bool*) – If False include only the nodes with nonzero clustering in the average.

Returns **avg** – Average clustering

Return type **float**

Examples

```
>>> G=nx.complete_graph(5)
>>> print(nx.average_clustering(G))
1.0
```

Notes

This is a space saving routine; it might be faster to use the clustering function to get a list and then take the average.

Self loops are ignored.

References

4.9.5 square_clustering

square_clustering(*G, nodes=None*)

Compute the squares clustering coefficient for nodes.

For each node return the fraction of possible squares that exist at the node ²⁶

$$C_4(v) = \frac{\sum_{u=1}^{k_v} \sum_{w=u+1}^{k_v} q_v(u, w)}{\sum_{u=1}^{k_v} \sum_{w=u+1}^{k_v} [a_v(u, w) + q_v(u, w)]},$$

where $q_v(u, w)$ are the number of common neighbors of u and w other than v (ie squares), and $a_v(u, w) = (k_u - (1 + q_v(u, w) + \theta_{uv}))(k_w - (1 + q_v(u, w) + \theta_{uw}))$, where $\theta_{uw} = 1$ if u and w are connected and 0 otherwise.

Parameters

- **G** (*graph*) –
- **nodes** (*container of nodes, optional (default=all nodes in G)*) – Compute clustering for nodes in this container.

Returns **c4** – A dictionary keyed by node with the square clustering coefficient value.

Return type **dictionary**

²⁶ Pedro G. Lind, Marta C. González, and Hans J. Herrmann. 2005 Cycles and clustering in bipartite networks. Physical Review E (72) 056127.

Examples

```
>>> G=nx.complete_graph(5)
>>> print(nx.square_clustering(G,0))
1.0
>>> print(nx.square_clustering(G))
{0: 1.0, 1: 1.0, 2: 1.0, 3: 1.0, 4: 1.0}
```

Notes

While $C_3(v)$ (triangle clustering) gives the probability that two neighbors of node v are connected with each other, $C_4(v)$ is the probability that two neighbors of node v share a common neighbor different from v . This algorithm can be applied to both bipartite and unipartite networks.

References

4.10 Coloring

4.11 Communities

4.11.1 K-Clique

`k_clique_communities(G, k[, cliques])` Find k-clique communities in graph using the percolation method.

`k_clique_communities`

`k_clique_communities(G, k, cliques=None)`

Find k-clique communities in graph using the percolation method.

A k-clique community is the union of all cliques of size k that can be reached through adjacent (sharing $k-1$ nodes) k-cliques.

Parameters

- **G** (*NetworkX graph*) –
- **k** (*int*) – Size of smallest clique
- **cliques** (*list or generator*) – Precomputed cliques (use `networkx.find_cliques(G)`)

Returns

Return type Yields sets of nodes, one for each k-clique community.

Examples

```
>>> G = nx.complete_graph(5)
>>> K5 = nx.convert_node_labels_to_integers(G, first_label=2)
```



```

>>> G.add_edges_from(K5.edges())
>>> c = list(nx.k_clique_communities(G, 4))
>>> list(c[0])
[0, 1, 2, 3, 4, 5, 6]
>>> list(nx.k_clique_communities(G, 6))
[]

```

References

4.12 Components

4.12.1 Connectivity

Connected components.

<code>is_connected(G)</code>	Return True if the graph is connected, false otherwise.
<code>number_connected_components(G)</code>	Return the number of connected components.
<code>connected_components(G)</code>	Generate connected components.
<code>connected_component_subgraphs(G[, copy])</code>	Generate connected components as subgraphs.
<code>node_connected_component(G, n)</code>	Return the nodes in the component of graph containing node n.

`is_connected`

`is_connected(G)`

Return True if the graph is connected, false otherwise.

Parameters *G* (*NetworkX Graph*) – An undirected graph.

Returns **connected** – True if the graph is connected, false otherwise.

Return type `bool`

Examples

```

>>> G = nx.path_graph(4)
>>> print(nx.is_connected(G))
True

```

See also:

`connected_components()`

Notes

For undirected graphs only.

`number_connected_components`

`number_connected_components(G)`

Return the number of connected components.

Parameters *G* (*NetworkX graph*) – An undirected graph.

Returns *n* – Number of connected components

Return type integer

See also:

`connected_components()`

Notes

For undirected graphs only.

connected_components

connected_components (*G*)

Generate connected components.

Parameters *G* (*NetworkX graph*) – An undirected graph

Returns *comp* – A generator of sets of nodes, one for each component of *G*.

Return type generator of sets

Examples

Generate a sorted list of connected components, largest first.

```
>>> G = nx.path_graph(4)
>>> G.add_path([10, 11, 12])
>>> [len(c) for c in sorted(nx.connected_components(G), key=len, reverse=True)]
[4, 3]
```

If you only want the largest connected component, it's more efficient to use `max` instead of `sort`.

```
>>> largest_cc = max(nx.connected_components(G), key=len)
```

See also:

`strongly_connected_components()`

Notes

For undirected graphs only.

connected_component_subgraphs

connected_component_subgraphs (*G*, *copy=True*)

Generate connected components as subgraphs.

Parameters

- *G* (*NetworkX graph*) – An undirected graph.
- *copy* (*bool* (*default=True*)) – If `True` make a copy of the graph attributes

Returns comp – A generator of graphs, one for each connected component of G.

Return type generator

Examples

```
>>> G = nx.path_graph(4)
>>> G.add_edge(5, 6)
>>> graphs = list(nx.connected_component_subgraphs(G))
```

If you only want the largest connected component, it's more efficient to use max than sort.

```
>>> Gc = max(nx.connected_component_subgraphs(G), key=len)
```

See also:

`connected_components()`

Notes

For undirected graphs only. Graph, node, and edge attributes are copied to the subgraphs by default.

node_connected_component

node_connected_component(G, n)

Return the nodes in the component of graph containing node n.

Parameters

- **G** (*NetworkX Graph*) – An undirected graph.
- **n** (*node label*) – A node in G

Returns comp – A set of nodes in the component of G containing node n.

Return type set

See also:

`connected_components()`

Notes

For undirected graphs only.

4.12.2 Strong connectivity

Strongly connected components.

<code>is_strongly_connected(G)</code>	Test directed graph for strong connectivity.
<code>number_strongly_connected_components(G)</code>	Return number of strongly connected components in graph.
<code>strongly_connected_components(G)</code>	Generate nodes in strongly connected components of graph.
<code>strongly_connected_component_subgraphs(G[, copy])</code>	Generate strongly connected components as subgraphs.
<code>strongly_connected_components_recursive(G)</code>	Generate nodes in strongly connected components of graph.
Continued on next page	

Table 4.41 – continued from previous page

<code>kosaraju_strongly_connected_components(G[, ...])</code>	Generate nodes in strongly connected components of graph.
<code>condensation(G[, scc])</code>	Returns the condensation of G.

is_strongly_connected

is_strongly_connected(G)

Test directed graph for strong connectivity.

Parameters **G** (*NetworkX Graph*) – A directed graph.

Returns **connected** – True if the graph is strongly connected, False otherwise.

Return type `bool`

See also:

`strongly_connected_components()`

Notes

For directed graphs only.

number_strongly_connected_components

number_strongly_connected_components(G)

Return number of strongly connected components in graph.

Parameters **G** (*NetworkX graph*) – A directed graph.

Returns **n** – Number of strongly connected components

Return type `integer`

See also:

`connected_components()`

Notes

For directed graphs only.

strongly_connected_components

strongly_connected_components(G)

Generate nodes in strongly connected components of graph.

Parameters **G** (*NetworkX Graph*) – An directed graph.

Returns **comp** – A generator of sets of nodes, one for each strongly connected component of G.

Return type `generator of sets`

Raises `NetworkXNotImplemented` – If G is undirected.

Examples

Generate a sorted list of strongly connected components, largest first.

```
>>> G = nx.cycle_graph(4, create_using=nx.DiGraph())
>>> G.add_cycle([10, 11, 12])
>>> [len(c) for c in sorted(nx.strongly_connected_components(G),
...                          key=len, reverse=True)]
[4, 3]
```

If you only want the largest component, it's more efficient to use `max` instead of `sort`.

```
>>> largest = max(nx.strongly_connected_components(G), key=len)
```

See also:

`connected_components()`, `weakly_connected_components()`

Notes

Uses Tarjan's algorithm with Nuutila's modifications. Nonrecursive version of algorithm.

References

strongly_connected_component_subgraphs

strongly_connected_component_subgraphs (*G*, *copy=True*)

Generate strongly connected components as subgraphs.

Parameters

- **G** (*NetworkX Graph*) – A directed graph.
- **copy** (*boolean, optional*) – if `copy` is `True`, Graph, node, and edge attributes are copied to the subgraphs.

Returns comp – A generator of graphs, one for each strongly connected component of *G*.

Return type generator of graphs

Examples

Generate a sorted list of strongly connected components, largest first.

```
>>> G = nx.cycle_graph(4, create_using=nx.DiGraph())
>>> G.add_cycle([10, 11, 12])
>>> [len(Gc) for Gc in sorted(nx.strongly_connected_component_subgraphs(G),
...                             key=len, reverse=True)]
[4, 3]
```

If you only want the largest component, it's more efficient to use `max` instead of `sort`.

```
>>> Gc = max(nx.strongly_connected_component_subgraphs(G), key=len)
```

See also:

`connected_component_subgraphs()`, `weakly_connected_component_subgraphs()`

strongly_connected_components_recursive

strongly_connected_components_recursive(*G*)

Generate nodes in strongly connected components of graph.

Recursive version of algorithm.

Parameters *G* (*NetworkX Graph*) – An directed graph.

Returns *comp* – A generator of sets of nodes, one for each strongly connected component of *G*.

Return type generator of sets

Raises *NetworkXNotImplemented* – If *G* is undirected

Examples

Generate a sorted list of strongly connected components, largest first.

```
>>> G = nx.cycle_graph(4, create_using=nx.DiGraph())
>>> G.add_cycle([10, 11, 12])
>>> [len(c) for c in sorted(nx.strongly_connected_components_recursive(G),
...                          key=len, reverse=True)]
[4, 3]
```

If you only want the largest component, it's more efficient to use `max` instead of `sort`.

```
>>> largest = max(nx.strongly_connected_components_recursive(G), key=len)
```

See also:

`connected_components()`

Notes

Uses Tarjan's algorithm with Nuutila's modifications.

References

kosaraju_strongly_connected_components

kosaraju_strongly_connected_components(*G*, *source=None*)

Generate nodes in strongly connected components of graph.

Parameters *G* (*NetworkX Graph*) – An directed graph.

Returns *comp* – A generator of sets of nodes, one for each strongly connected component of *G*.

Return type generator of sets

Raises *NetworkXNotImplemented* – If *G* is undirected.

Examples

Generate a sorted list of strongly connected components, largest first.

```
>>> G = nx.cycle_graph(4, create_using=nx.DiGraph())
>>> G.add_cycle([10, 11, 12])
>>> [len(c) for c in sorted(nx.kosaraju_strongly_connected_components(G),
...                          key=len, reverse=True)]
[4, 3]
```

If you only want the largest component, it's more efficient to use `max` instead of `sort`.

```
>>> largest = max(nx.kosaraju_strongly_connected_components(G), key=len)
```

See also:

`connected_components()`, `weakly_connected_components()`

Notes

Uses Kosaraju's algorithm.

condensation

condensation(*G*, *scc=None*)

Returns the condensation of *G*.

The condensation of *G* is the graph with each of the strongly connected components contracted into a single node.

Parameters

- **G** (*NetworkX DiGraph*) – A directed graph.
- **scc** (*list or generator (optional, default=None)*) – Strongly connected components. If provided, the elements in *scc* must partition the nodes in *G*. If not provided, it will be calculated as `scc=nx.strongly_connected_components(G)`.

Returns **C** – The condensation graph *C* of *G*. The node labels are integers corresponding to the index of the component in the list of strongly connected components of *G*. *C* has a graph attribute named 'mapping' with a dictionary mapping the original nodes to the nodes in *C* to which they belong. Each node in *C* also has a node attribute 'members' with the set of original nodes in *G* that form the SCC that the node in *C* represents.

Return type *NetworkX DiGraph*

Raises *NetworkXNotImplemented* – If *G* is not directed

Notes

After contracting all strongly connected components to a single node, the resulting graph is a directed acyclic graph.

4.12.3 Weak connectivity

Weakly connected components.

`is_weakly_connected(G)`

Test directed graph for weak connectivity.

Continued on next page

Table 4.42 – continued from previous page

<code>number_weakly_connected_components(G)</code>	Return the number of weakly connected components in G.
<code>weakly_connected_components(G)</code>	Generate weakly connected components of G.
<code>weakly_connected_component_subgraphs(G[, copy])</code>	Generate weakly connected components as subgraphs.

is_weakly_connected

is_weakly_connected(G)

Test directed graph for weak connectivity.

A directed graph is weakly connected if, and only if, the graph is connected when the direction of the edge between nodes is ignored.

Parameters *G* (*NetworkX Graph*) – A directed graph.

Returns **connected** – True if the graph is weakly connected, False otherwise.

Return type `bool`

See also:

`is_strongly_connected()`, `is_semiconnected()`, `is_connected()`

Notes

For directed graphs only.

number_weakly_connected_components

number_weakly_connected_components(G)

Return the number of weakly connected components in G.

Parameters *G* (*NetworkX graph*) – A directed graph.

Returns **n** – Number of weakly connected components

Return type `integer`

See also:

`connected_components()`

Notes

For directed graphs only.

weakly_connected_components

weakly_connected_components(G)

Generate weakly connected components of G.

Parameters *G* (*NetworkX graph*) – A directed graph

Returns **comp** – A generator of sets of nodes, one for each weakly connected component of G.

Return type `generator of sets`

Examples

Generate a sorted list of weakly connected components, largest first.

```
>>> G = nx.path_graph(4, create_using=nx.DiGraph())
>>> G.add_path([10, 11, 12])
>>> [len(c) for c in sorted(nx.weakly_connected_components(G),
...                          key=len, reverse=True)]
[4, 3]
```

If you only want the largest component, it's more efficient to use `max` instead of `sort`.

```
>>> largest_cc = max(nx.weakly_connected_components(G), key=len)
```

See also:

`strongly_connected_components()`

Notes

For directed graphs only.

weakly_connected_component_subgraphs

weakly_connected_component_subgraphs (*G*, *copy=True*)

Generate weakly connected components as subgraphs.

Parameters

- **G** (*NetworkX graph*) – A directed graph.
- **copy** (*bool (default=True)*) – If True make a copy of the graph attributes

Returns **comp** – A generator of graphs, one for each weakly connected component of *G*.

Return type generator

Examples

Generate a sorted list of weakly connected components, largest first.

```
>>> G = nx.path_graph(4, create_using=nx.DiGraph())
>>> G.add_path([10, 11, 12])
>>> [len(c) for c in sorted(nx.weakly_connected_component_subgraphs(G),
...                          key=len, reverse=True)]
[4, 3]
```

If you only want the largest component, it's more efficient to use `max` instead of `sort`.

```
>>> Gc = max(nx.weakly_connected_component_subgraphs(G), key=len)
```

See also:

`strongly_connected_components()`, `connected_components()`

Notes

For directed graphs only. Graph, node, and edge attributes are copied to the subgraphs by default.

4.12.4 Attracting components

Attracting components.

<code>is_attracting_component(G)</code>	Returns True if G consists of a single attracting component.
<code>number_attracting_components(G)</code>	Returns the number of attracting components in G .
<code>attracting_components(G)</code>	Generates a list of attracting components in G .
<code>attracting_component_subgraphs(G[, copy])</code>	Generates a list of attracting component subgraphs from G .

is_attracting_component

is_attracting_component (G)

Returns True if G consists of a single attracting component.

Parameters G (*DiGraph*, *MultiDiGraph*) – The graph to be analyzed.

Returns **attracting** – True if G has a single attracting component. Otherwise, False.

Return type `bool`

See also:

`attracting_components()`, `number_attracting_components()`,
`attracting_component_subgraphs()`

number_attracting_components

number_attracting_components (G)

Returns the number of attracting components in G .

Parameters G (*DiGraph*, *MultiDiGraph*) – The graph to be analyzed.

Returns **n** – The number of attracting components in G .

Return type `int`

See also:

`attracting_components()`, `is_attracting_component()`, `attracting_component_subgraphs()`

attracting_components

attracting_components (G)

Generates a list of attracting components in G .

An attracting component in a directed graph G is a strongly connected component with the property that a random walker on the graph will never leave the component, once it enters the component.

The nodes in attracting components can also be thought of as recurrent nodes. If a random walker enters the attractor containing the node, then the node will be visited infinitely often.

Parameters G (*DiGraph*, *MultiDiGraph*) – The graph to be analyzed.

Returns `attractors` – A generator of sets of nodes, one for each attracting component of `G`.

Return type generator of sets

See also:

`number_attracting_components()`, `is_attracting_component()`,
`attracting_component_subgraphs()`

`attracting_component_subgraphs`

`attracting_component_subgraphs` (`G`, `copy=True`)

Generates a list of attracting component subgraphs from `G`.

Parameters `G` (*DiGraph*, *MultiDiGraph*) – The graph to be analyzed.

Returns

- **`subgraphs`** (*list*) – A list of node-induced subgraphs of the attracting components of `G`.
- **`copy`** (*bool*) – If `copy` is `True`, graph, node, and edge attributes are copied to the subgraphs.

See also:

`attracting_components()`, `number_attracting_components()`,
`is_attracting_component()`

4.12.5 Biconnected components

Biconnected components and articulation points.

<code>is_biconnected(G)</code>	Return <code>True</code> if the graph is biconnected, <code>False</code> otherwise.
<code>biconnected_components(G)</code>	Return a generator of sets of nodes, one set for each biconnected
<code>biconnected_component_edges(G)</code>	Return a generator of lists of edges, one list for each biconnected compon
<code>biconnected_component_subgraphs(G[, copy])</code>	Return a generator of graphs, one graph for each biconnected component
<code>articulation_points(G)</code>	Return a generator of articulation points, or cut vertices, of a graph.

`is_biconnected`

`is_biconnected` (`G`)

Return `True` if the graph is biconnected, `False` otherwise.

A graph is biconnected if, and only if, it cannot be disconnected by removing only one node (and all edges incident on that node). If removing a node increases the number of disconnected components in the graph, that node is called an articulation point, or cut vertex. A biconnected graph has no articulation points.

Parameters `G` (*NetworkX Graph*) – An undirected graph.

Returns `biconnected` – `True` if the graph is biconnected, `False` otherwise.

Return type `bool`

Raises `NetworkXNotImplemented` – If the input graph is not undirected.

Examples

```
>>> G = nx.path_graph(4)
>>> print(nx.is_biconnected(G))
False
>>> G.add_edge(0, 3)
>>> print(nx.is_biconnected(G))
True
```

See also:

biconnected_components(), *articulation_points()*, *biconnected_component_edges()*, *biconnected_component_subgraphs()*

Notes

The algorithm to find articulation points and biconnected components is implemented using a non-recursive depth-first-search (DFS) that keeps track of the highest level that back edges reach in the DFS tree. A node n is an articulation point if, and only if, there exists a subtree rooted at n such that there is no back edge from any successor of n that links to a predecessor of n in the DFS tree. By keeping track of all the edges traversed by the DFS we can obtain the biconnected components because all edges of a bicomponent will be traversed consecutively between articulation points.

References

biconnected_components

biconnected_components(*G*)

Return a generator of sets of nodes, one set for each biconnected component of the graph

Biconnected components are maximal subgraphs such that the removal of a node (and all edges incident on that node) will not disconnect the subgraph. Note that nodes may be part of more than one biconnected component. Those nodes are articulation points, or cut vertices. The removal of articulation points will increase the number of connected components of the graph.

Notice that by convention a dyad is considered a biconnected component.

Parameters *G* (*NetworkX Graph*) – An undirected graph.

Returns *nodes* – Generator of sets of nodes, one set for each biconnected component.

Return type generator

Raises *NetworkXNotImplemented* – If the input graph is not undirected.

Examples

```
>>> G = nx.lollipop_graph(5, 1)
>>> print(nx.is_biconnected(G))
False
>>> bicomponents = list(nx.biconnected_components(G))
>>> len(bicomponents)
2
>>> G.add_edge(0, 5)
>>> print(nx.is_biconnected(G))
```

```
True
>>> bicomponents = list(nx.biconnected_components(G))
>>> len(bicomponents)
1
```

You can generate a sorted list of biconnected components, largest first, using sort.

```
>>> G.remove_edge(0, 5)
>>> [len(c) for c in sorted(nx.biconnected_components(G), key=len, reverse=True)]
[5, 2]
```

If you only want the largest connected component, it's more efficient to use max instead of sort.

```
>>> Gc = max(nx.biconnected_components(G), key=len)
```

See also:

is_biconnected(), *articulation_points()*, *biconnected_component_edges()*,
biconnected_component_subgraphs()

Notes

The algorithm to find articulation points and biconnected components is implemented using a non-recursive depth-first-search (DFS) that keeps track of the highest level that back edges reach in the DFS tree. A node n is an articulation point if, and only if, there exists a subtree rooted at n such that there is no back edge from any successor of n that links to a predecessor of n in the DFS tree. By keeping track of all the edges traversed by the DFS we can obtain the biconnected components because all edges of a bicomponent will be traversed consecutively between articulation points.

References

biconnected_component_edges

biconnected_component_edges(G)

Return a generator of lists of edges, one list for each biconnected component of the input graph.

Biconnected components are maximal subgraphs such that the removal of a node (and all edges incident on that node) will not disconnect the subgraph. Note that nodes may be part of more than one biconnected component. Those nodes are articulation points, or cut vertices. However, each edge belongs to one, and only one, biconnected component.

Notice that by convention a dyad is considered a biconnected component.

Parameters G (*NetworkX Graph*) – An undirected graph.

Returns *edges* – Generator of lists of edges, one list for each bicomponent.

Return type generator of lists

Raises *NetworkXNotImplemented* – If the input graph is not undirected.

Examples

```
>>> G = nx.barbell_graph(4, 2)
>>> print(nx.is_biconnected(G))
False
```

```
>>> bicomponents_edges = list(nx.biconnected_component_edges(G))
>>> len(bicomponents_edges)
5
>>> G.add_edge(2, 8)
>>> print(nx.is_biconnected(G))
True
>>> bicomponents_edges = list(nx.biconnected_component_edges(G))
>>> len(bicomponents_edges)
1
```

See also:

is_biconnected(), *biconnected_components()*, *articulation_points()*,
biconnected_component_subgraphs()

Notes

The algorithm to find articulation points and biconnected components is implemented using a non-recursive depth-first-search (DFS) that keeps track of the highest level that back edges reach in the DFS tree. A node n is an articulation point if, and only if, there exists a subtree rooted at n such that there is no back edge from any successor of n that links to a predecessor of n in the DFS tree. By keeping track of all the edges traversed by the DFS we can obtain the biconnected components because all edges of a bicomponent will be traversed consecutively between articulation points.

References**biconnected_component_subgraphs**

biconnected_component_subgraphs (G , *copy=True*)

Return a generator of graphs, one graph for each biconnected component of the input graph.

Biconnected components are maximal subgraphs such that the removal of a node (and all edges incident on that node) will not disconnect the subgraph. Note that nodes may be part of more than one biconnected component. Those nodes are articulation points, or cut vertices. The removal of articulation points will increase the number of connected components of the graph.

Notice that by convention a dyad is considered a biconnected component.

Parameters G (*NetworkX Graph*) – An undirected graph.

Returns **graphs** – Generator of graphs, one graph for each biconnected component.

Return type generator

Raises `NetworkXNotImplemented` – If the input graph is not undirected.

Examples

```
>>> G = nx.lollipop_graph(5, 1)
>>> print(nx.is_biconnected(G))
False
>>> bicomponents = list(nx.biconnected_component_subgraphs(G))
>>> len(bicomponents)
2
>>> G.add_edge(0, 5)
>>> print(nx.is_biconnected(G))
```

```
True
>>> bicomponents = list(nx.biconnected_component_subgraphs(G))
>>> len(bicomponents)
1
```

You can generate a sorted list of biconnected components, largest first, using sort.

```
>>> G.remove_edge(0, 5)
>>> [len(c) for c in sorted(nx.biconnected_component_subgraphs(G),
...                          key=len, reverse=True)]
[5, 2]
```

If you only want the largest connected component, it's more efficient to use max instead of sort.

```
>>> Gc = max(nx.biconnected_component_subgraphs(G), key=len)
```

See also:

`is_biconnected()`, `articulation_points()`, `biconnected_component_edges()`,
`biconnected_components()`

Notes

The algorithm to find articulation points and biconnected components is implemented using a non-recursive depth-first-search (DFS) that keeps track of the highest level that back edges reach in the DFS tree. A node n is an articulation point if, and only if, there exists a subtree rooted at n such that there is no back edge from any successor of n that links to a predecessor of n in the DFS tree. By keeping track of all the edges traversed by the DFS we can obtain the biconnected components because all edges of a bicomponent will be traversed consecutively between articulation points.

Graph, node, and edge attributes are copied to the subgraphs.

References

articulation_points

`articulation_points(G)`

Return a generator of articulation points, or cut vertices, of a graph.

An articulation point or cut vertex is any node whose removal (along with all its incident edges) increases the number of connected components of a graph. An undirected connected graph without articulation points is biconnected. Articulation points belong to more than one biconnected component of a graph.

Notice that by convention a dyad is considered a biconnected component.

Parameters *G* (*NetworkX Graph*) – An undirected graph.

Returns *articulation points* – generator of nodes

Return type generator

Raises `NetworkXNotImplemented` – If the input graph is not undirected.

Examples

```
>>> G = nx.barbell_graph(4, 2)
>>> print(nx.is_biconnected(G))
False
>>> len(list(nx.articulation_points(G)))
4
>>> G.add_edge(2, 8)
>>> print(nx.is_biconnected(G))
True
>>> len(list(nx.articulation_points(G)))
0
```

See also:

is_biconnected(), *biconnected_components()*, *biconnected_component_edges()*,
biconnected_component_subgraphs()

Notes

The algorithm to find articulation points and biconnected components is implemented using a non-recursive depth-first-search (DFS) that keeps track of the highest level that back edges reach in the DFS tree. A node n is an articulation point if, and only if, there exists a subtree rooted at n such that there is no back edge from any successor of n that links to a predecessor of n in the DFS tree. By keeping track of all the edges traversed by the DFS we can obtain the biconnected components because all edges of a bicomponent will be traversed consecutively between articulation points.

References

4.12.6 Semiconnectedness

Semiconnectedness.

is_semiconnected(G) Return True if the graph is semiconnected, False otherwise.

is_semiconnected

is_semiconnected(G)

Return True if the graph is semiconnected, False otherwise.

A graph is semiconnected if, and only if, for any pair of nodes, either one is reachable from the other, or they are mutually reachable.

Parameters **G** (*NetworkX graph*) – A directed graph.

Returns **semiconnected** – True if the graph is semiconnected, False otherwise.

Return type **bool**

Raises

- `NetworkXNotImplemented` – If the input graph is not directed.
- `NetworkXPointlessConcept` – If the graph is empty.

Examples

```
>>> G=nx.path_graph(4,create_using=nx.DiGraph())
>>> print(nx.is_semiconnected(G))
True
>>> G=nx.DiGraph([(1, 2), (3, 2)])
>>> print(nx.is_semiconnected(G))
False
```

See also:

`is_strongly_connected()`, `is_weakly_connected()`

4.13 Connectivity

Connectivity and cut algorithms

4.13.1 K-node-components

Moody and White algorithm for k-components

`k_components(G[, flow_func])` Returns the k-component structure of a graph G.

`k_components`

`k_components(G, flow_func=None)`

Returns the k-component structure of a graph G.

A k -component is a maximal subgraph of a graph G that has, at least, node connectivity k : we need to remove at least k nodes to break it into more components. k -components have an inherent hierarchical structure because they are nested in terms of connectivity: a connected graph can contain several 2-components, each of which can contain one or more 3-components, and so forth.

Parameters

- **G** (*NetworkX graph*) –
- **flow_func** (*function*) – Function to perform the underlying flow computations. Default value `edmonds_karp()`. This function performs better in sparse graphs with right tailed degree distributions. `shortest_augmenting_path()` will perform better in denser graphs.

Returns `k_components` – Dictionary with all connectivity levels k in the input Graph as keys and a list of sets of nodes that form a k-component of level k as values.

Return type `dict`

Raises `NetworkXNotImplemented` – If the input graph is directed.

Examples

```
>>> # Petersen graph has 10 nodes and it is triconnected, thus all
>>> # nodes are in a single component on all three connectivity levels
```

```
>>> G = nx.petersen_graph()
>>> k_components = nx.k_components(G)
```

Notes

Moody and White ²⁷ (appendix A) provide an algorithm for identifying k-components in a graph, which is based on Kanevsky's algorithm ²⁸ for finding all minimum-size node cut-sets of a graph (implemented in `all_node_cuts()` function):

1. Compute node connectivity, k , of the input graph G .
2. Identify all k -cutsets at the current level of connectivity using Kanevsky's algorithm.
3. Generate new graph components based on the removal of these cutsets. Nodes in a cutset belong to both sides of the induced cut.
4. If the graph is neither complete nor trivial, return to 1; else end.

This implementation also uses some heuristics (see ²⁹ for details) to speed up the computation.

See also:

`node_connectivity()`, `all_node_cuts()`

References

4.13.2 K-node-cutsets

Kanevsky all minimum node k cutsets algorithm.

`all_node_cuts(G[, k, flow_func])` Returns all minimum k cutsets of an undirected graph G .

`all_node_cuts`

`all_node_cuts` (G , $k=None$, $flow_func=None$)

Returns all minimum k cutsets of an undirected graph G .

This implementation is based on Kanevsky's algorithm ³⁰ for finding all minimum-size node cut-sets of an undirected graph G ; ie the set (or sets) of nodes of cardinality equal to the node connectivity of G . Thus if removed, would break G into two or more connected components.

Parameters

- **G** (*NetworkX graph*) – Undirected graph
- **k** (*Integer*) – Node connectivity of the input graph. If k is `None`, then it is computed. Default value: `None`.

²⁷ Moody, J. and D. White (2003). Social cohesion and embeddedness: A hierarchical conception of social groups. *American Sociological Review* 68(1), 103–28. <http://www2.asanet.org/journals/ASRFeb03MoodyWhite.pdf>

²⁸ Kanevsky, A. (1993). Finding all minimum-size separating vertex sets in a graph. *Networks* 23(6), 533–541. <http://onlinelibrary.wiley.com/doi/10.1002/net.3230230604/abstract>

²⁹ Torrents, J. and F. Ferraro (2015). Structural Cohesion: Visualization and Heuristics for Fast Computation. <http://arxiv.org/pdf/1503.04476v1>

³⁰ Kanevsky, A. (1993). Finding all minimum-size separating vertex sets in a graph. *Networks* 23(6), 533–541. <http://onlinelibrary.wiley.com/doi/10.1002/net.3230230604/abstract>

- **flow_func** (*function*) – Function to perform the underlying flow computations. Default value `edmonds_karp`. This function performs better in sparse graphs with right tailed degree distributions. `shortest_augmenting_path` will perform better in denser graphs.

Returns `cuts` – Each node cutset has cardinality equal to the node connectivity of the input graph.

Return type a generator of node cutsets

Examples

```
>>> # A two-dimensional grid graph has 4 cutsets of cardinality 2
>>> G = nx.grid_2d_graph(5, 5)
>>> cutsets = list(nx.all_node_cuts(G))
>>> len(cutsets)
4
>>> all(2 == len(cutset) for cutset in cutsets)
True
>>> nx.node_connectivity(G)
2
```

Notes

This implementation is based on the sequential algorithm for finding all minimum-size separating vertex sets in a graph¹. The main idea is to compute minimum cuts using local maximum flow computations among a set of nodes of highest degree and all other non-adjacent nodes in the Graph. Once we find a minimum cut, we add an edge between the high degree node and the target node of the local maximum flow computation to make sure that we will not find that minimum cut again.

See also:

`node_connectivity()`, `edmonds_karp()`, `shortest_augmenting_path()`

References

4.13.3 Flow-based Connectivity

Flow based connectivity algorithms

<code>average_node_connectivity(G[, flow_func])</code>	Returns the average connectivity of a graph G.
<code>all_pairs_node_connectivity(G[, nbunch, ...])</code>	Compute node connectivity between all pairs of nodes of G.
<code>edge_connectivity(G[, s, t, flow_func])</code>	Returns the edge connectivity of the graph or digraph G.
<code>local_edge_connectivity(G, u, v[, ...])</code>	Returns local edge connectivity for nodes s and t in G.
<code>local_node_connectivity(G, s, t[, ...])</code>	Computes local node connectivity for nodes s and t.
<code>node_connectivity(G[, s, t, flow_func])</code>	Returns node connectivity for a graph or digraph G.

average_node_connectivity

average_node_connectivity (*G*, *flow_func=None*)

Returns the average connectivity of a graph G.

The average connectivity $\bar{\kappa}$ of a graph G is the average of local node connectivity over all pairs of nodes of G³¹

³¹ Beineke, L., O. Oellermann, and R. Pippert (2002). The average connectivity of a graph. Discrete mathematics 252(1-3), 31-45.

$$\bar{\kappa}(G) = \frac{\sum_{u,v} \kappa_G(u,v)}{\binom{n}{2}}$$

Parameters

- **G** (*NetworkX graph*) – Undirected graph
- **flow_func** (*function*) – A function for computing the maximum flow among a pair of nodes. The function has to accept at least three parameters: a Digraph, a source node, and a target node. And return a residual network that follows NetworkX conventions (see `maximum_flow()` for details). If `flow_func` is `None`, the default maximum flow function (`edmonds_karp()`) is used. See `local_node_connectivity()` for details. The choice of the default function may change from version to version and should not be relied on. Default value: `None`.

Returns **K** – Average node connectivity

Return type `float`

See also:

`local_node_connectivity()`, `node_connectivity()`, `edge_connectivity()`,
`maximum_flow()`, `edmonds_karp()`, `preflow_push()`, `shortest_augmenting_path()`

References**all_pairs_node_connectivity**

all_pairs_node_connectivity (*G, nbunch=None, flow_func=None*)

Compute node connectivity between all pairs of nodes of G.

Parameters

- **G** (*NetworkX graph*) – Undirected graph
- **nbunch** (*container*) – Container of nodes. If provided node connectivity will be computed only over pairs of nodes in `nbunch`.
- **flow_func** (*function*) – A function for computing the maximum flow among a pair of nodes. The function has to accept at least three parameters: a Digraph, a source node, and a target node. And return a residual network that follows NetworkX conventions (see `maximum_flow()` for details). If `flow_func` is `None`, the default maximum flow function (`edmonds_karp()`) is used. See below for details. The choice of the default function may change from version to version and should not be relied on. Default value: `None`.

Returns **all_pairs** – A dictionary with node connectivity between all pairs of nodes in G, or in `nbunch` if provided.

Return type `dict`

See also:

`local_node_connectivity()`, `edge_connectivity()`, `local_edge_connectivity()`,
`maximum_flow()`, `edmonds_karp()`, `preflow_push()`, `shortest_augmenting_path()`

<http://www.sciencedirect.com/science/article/pii/S0012365X01001807>

edge_connectivity

edge_connectivity (*G*, *s=None*, *t=None*, *flow_func=None*)

Returns the edge connectivity of the graph or digraph *G*.

The edge connectivity is equal to the minimum number of edges that must be removed to disconnect *G* or render it trivial. If source and target nodes are provided, this function returns the local edge connectivity: the minimum number of edges that must be removed to break all paths from source to target in *G*.

Parameters

- **G** (*NetworkX graph*) – Undirected or directed graph
- **s** (*node*) – Source node. Optional. Default value: None.
- **t** (*node*) – Target node. Optional. Default value: None.
- **flow_func** (*function*) – A function for computing the maximum flow among a pair of nodes. The function has to accept at least three parameters: a Digraph, a source node, and a target node. And return a residual network that follows NetworkX conventions (see `maximum_flow()` for details). If `flow_func` is None, the default maximum flow function (`edmonds_karp()`) is used. See below for details. The choice of the default function may change from version to version and should not be relied on. Default value: None.

Returns **K** – Edge connectivity for *G*, or local edge connectivity if source and target were provided

Return type integer

Examples

```
>>> # Platonic icosahedral graph is 5-edge-connected
>>> G = nx.icosahedral_graph()
>>> nx.edge_connectivity(G)
5
```

You can use alternative flow algorithms for the underlying maximum flow computation. In dense networks the algorithm `shortest_augmenting_path()` will usually perform better than the default `edmonds_karp()`, which is faster for sparse networks with highly skewed degree distributions. Alternative flow functions have to be explicitly imported from the flow package.

```
>>> from networkx.algorithms.flow import shortest_augmenting_path
>>> nx.edge_connectivity(G, flow_func=shortest_augmenting_path)
5
```

If you specify a pair of nodes (source and target) as parameters, this function returns the value of local edge connectivity.

```
>>> nx.edge_connectivity(G, 3, 7)
5
```

If you need to perform several local computations among different pairs of nodes on the same graph, it is recommended that you reuse the data structures used in the maximum flow computations. See `local_edge_connectivity()` for details.

Notes

This is a flow based implementation of global edge connectivity. For undirected graphs the algorithm works by finding a ‘small’ dominating set of nodes of G (see algorithm 7 in ³²) and computing local maximum flow (see `local_edge_connectivity()`) between an arbitrary node in the dominating set and the rest of nodes in it. This is an implementation of algorithm 6 in ¹. For directed graphs, the algorithm does n calls to the maximum flow function. This is an implementation of algorithm 8 in ¹.

See also:

`local_edge_connectivity()`, `local_node_connectivity()`, `node_connectivity()`, `maximum_flow()`, `edmonds_karp()`, `preflow_push()`, `shortest_augmenting_path()`

References

`local_edge_connectivity`

`local_edge_connectivity` ($G, u, v, flow_func=None, auxiliary=None, residual=None, cutoff=None$)

Returns local edge connectivity for nodes s and t in G .

Local edge connectivity for two nodes s and t is the minimum number of edges that must be removed to disconnect them.

This is a flow based implementation of edge connectivity. We compute the maximum flow on an auxiliary digraph build from the original network (see below for details). This is equal to the local edge connectivity because the value of a maximum s - t -flow is equal to the capacity of a minimum s - t -cut (Ford and Fulkerson theorem) ³³.

Parameters

- **G** (*NetworkX graph*) – Undirected or directed graph
- **s** (*node*) – Source node
- **t** (*node*) – Target node
- **`flow_func`** (*function*) – A function for computing the maximum flow among a pair of nodes. The function has to accept at least three parameters: a Digraph, a source node, and a target node. And return a residual network that follows NetworkX conventions (see `maximum_flow()` for details). If `flow_func` is `None`, the default maximum flow function (`edmonds_karp()`) is used. See below for details. The choice of the default function may change from version to version and should not be relied on. Default value: `None`.
- **`auxiliary`** (*NetworkX DiGraph*) – Auxiliary digraph for computing flow based edge connectivity. If provided it will be reused instead of recreated. Default value: `None`.
- **`residual`** (*NetworkX DiGraph*) – Residual network to compute maximum flow. If provided it will be reused instead of recreated. Default value: `None`.
- **`cutoff`** (*integer, float*) – If specified, the maximum flow algorithm will terminate when the flow value reaches or exceeds the cutoff. This is only for the algorithms that support the cutoff parameter: `edmonds_karp()` and `shortest_augmenting_path()`. Other algorithms will ignore this parameter. Default value: `None`.

Returns **K** – local edge connectivity for nodes s and t .

Return type `integer`

³² Abdol-Hossein Esfahanian. Connectivity Algorithms. http://www.cse.msu.edu/~cse835/Papers/Graph_connectivity_revised.pdf

³³ Abdol-Hossein Esfahanian. Connectivity Algorithms. http://www.cse.msu.edu/~cse835/Papers/Graph_connectivity_revised.pdf

Examples

This function is not imported in the base NetworkX namespace, so you have to explicitly import it from the connectivity package:

```
>>> from networkx.algorithms.connectivity import local_edge_connectivity
```

We use in this example the platonic icosahedral graph, which has edge connectivity 5.

```
>>> G = nx.icosahedral_graph()
>>> local_edge_connectivity(G, 0, 6)
5
```

If you need to compute local connectivity on several pairs of nodes in the same graph, it is recommended that you reuse the data structures that NetworkX uses in the computation: the auxiliary digraph for edge connectivity, and the residual network for the underlying maximum flow computation.

Example of how to compute local edge connectivity among all pairs of nodes of the platonic icosahedral graph reusing the data structures.

```
>>> import itertools
>>> # You also have to explicitly import the function for
>>> # building the auxiliary digraph from the connectivity package
>>> from networkx.algorithms.connectivity import (
...     build_auxiliary_edge_connectivity)
>>> H = build_auxiliary_edge_connectivity(G)
>>> # And the function for building the residual network from the
>>> # flow package
>>> from networkx.algorithms.flow import build_residual_network
>>> # Note that the auxiliary digraph has an edge attribute named capacity
>>> R = build_residual_network(H, 'capacity')
>>> result = dict.fromkeys(G, dict())
>>> # Reuse the auxiliary digraph and the residual network by passing them
>>> # as parameters
>>> for u, v in itertools.combinations(G, 2):
...     k = local_edge_connectivity(G, u, v, auxiliary=H, residual=R)
...     result[u][v] = k
>>> all(result[u][v] == 5 for u, v in itertools.combinations(G, 2))
True
```

You can also use alternative flow algorithms for computing edge connectivity. For instance, in dense networks the algorithm `shortest_augmenting_path()` will usually perform better than the default `edmonds_karp()` which is faster for sparse networks with highly skewed degree distributions. Alternative flow functions have to be explicitly imported from the flow package.

```
>>> from networkx.algorithms.flow import shortest_augmenting_path
>>> local_edge_connectivity(G, 0, 6, flow_func=shortest_augmenting_path)
5
```

Notes

This is a flow based implementation of edge connectivity. We compute the maximum flow using, by default, the `edmonds_karp()` algorithm on an auxiliary digraph build from the original input graph:

If the input graph is undirected, we replace each edge (u, v) with two reciprocal arcs (u, v) and (v, u) and then we set the attribute ‘capacity’ for each arc to 1. If the input graph is directed we simply add the ‘capacity’ attribute. This is an implementation of algorithm 1 in ¹.

The maximum flow in the auxiliary network is equal to the local edge connectivity because the value of a maximum s-t-flow is equal to the capacity of a minimum s-t-cut (Ford and Fulkerson theorem).

See also:

`edge_connectivity()`, `local_node_connectivity()`, `node_connectivity()`,
`maximum_flow()`, `edmonds_karp()`, `preflow_push()`, `shortest_augmenting_path()`

References

local_node_connectivity

local_node_connectivity(*G*, *s*, *t*, *flow_func*=None, *auxiliary*=None, *residual*=None, *cutoff*=None)

Computes local node connectivity for nodes *s* and *t*.

Local node connectivity for two non adjacent nodes *s* and *t* is the minimum number of nodes that must be removed (along with their incident edges) to disconnect them.

This is a flow based implementation of node connectivity. We compute the maximum flow on an auxiliary digraph build from the original input graph (see below for details).

Parameters

- **G** (*NetworkX graph*) – Undirected graph
- **s** (*node*) – Source node
- **t** (*node*) – Target node
- **flow_func** (*function*) – A function for computing the maximum flow among a pair of nodes. The function has to accept at least three parameters: a Digraph, a source node, and a target node. And return a residual network that follows NetworkX conventions (see `maximum_flow()` for details). If `flow_func` is None, the default maximum flow function (`edmonds_karp()`) is used. See below for details. The choice of the default function may change from version to version and should not be relied on. Default value: None.
- **auxiliary** (*NetworkX DiGraph*) – Auxiliary digraph to compute flow based node connectivity. It has to have a graph attribute called `mapping` with a dictionary mapping node names in *G* and in the auxiliary digraph. If provided it will be reused instead of recreated. Default value: None.
- **residual** (*NetworkX DiGraph*) – Residual network to compute maximum flow. If provided it will be reused instead of recreated. Default value: None.
- **cutoff** (*integer, float*) – If specified, the maximum flow algorithm will terminate when the flow value reaches or exceeds the cutoff. This is only for the algorithms that support the cutoff parameter: `edmonds_karp()` and `shortest_augmenting_path()`. Other algorithms will ignore this parameter. Default value: None.

Returns **K** – local node connectivity for nodes *s* and *t*

Return type integer

Examples

This function is not imported in the base NetworkX namespace, so you have to explicitly import it from the connectivity package:


```
>>> from networkx.algorithms.connectivity import local_node_connectivity
```

We use in this example the platonic icosahedral graph, which has node connectivity 5.

```
>>> G = nx.icosahedral_graph()
>>> local_node_connectivity(G, 0, 6)
5
```

If you need to compute local connectivity on several pairs of nodes in the same graph, it is recommended that you reuse the data structures that NetworkX uses in the computation: the auxiliary digraph for node connectivity, and the residual network for the underlying maximum flow computation.

Example of how to compute local node connectivity among all pairs of nodes of the platonic icosahedral graph reusing the data structures.

```
>>> import itertools
>>> # You also have to explicitly import the function for
>>> # building the auxiliary digraph from the connectivity package
>>> from networkx.algorithms.connectivity import (
...     build_auxiliary_node_connectivity)
...
>>> H = build_auxiliary_node_connectivity(G)
>>> # And the function for building the residual network from the
>>> # flow package
>>> from networkx.algorithms.flow import build_residual_network
>>> # Note that the auxiliary digraph has an edge attribute named capacity
>>> R = build_residual_network(H, 'capacity')
>>> result = dict.fromkeys(G, dict())
>>> # Reuse the auxiliary digraph and the residual network by passing them
>>> # as parameters
>>> for u, v in itertools.combinations(G, 2):
...     k = local_node_connectivity(G, u, v, auxiliary=H, residual=R)
...     result[u][v] = k
...
>>> all(result[u][v] == 5 for u, v in itertools.combinations(G, 2))
True
```

You can also use alternative flow algorithms for computing node connectivity. For instance, in dense networks the algorithm `shortest_augmenting_path()` will usually perform better than the default `edmonds_karp()` which is faster for sparse networks with highly skewed degree distributions. Alternative flow functions have to be explicitly imported from the flow package.

```
>>> from networkx.algorithms.flow import shortest_augmenting_path
>>> local_node_connectivity(G, 0, 6, flow_func=shortest_augmenting_path)
5
```

Notes

This is a flow based implementation of node connectivity. We compute the maximum flow using, by default, the `edmonds_karp()` algorithm (see: `maximum_flow()`) on an auxiliary digraph build from the original input graph:

For an undirected graph G having n nodes and m edges we derive a directed graph H with $2n$ nodes and $2m + n$ arcs by replacing each original node v with two nodes v_A, v_B linked by an (internal) arc in H . Then for each edge (u, v) in G we add two arcs (u_B, v_A) and (v_B, u_A) in H . Finally we set the attribute `capacity = 1` for each arc in H ³⁴.

³⁴ Kammer, Frank and Hanjo Taubig. Graph Connectivity. in Brandes and Erlebach, 'Network Analysis: Method-

For a directed graph G having n nodes and m arcs we derive a directed graph H with $2n$ nodes and $m + n$ arcs by replacing each original node v with two nodes v_A, v_B linked by an (internal) arc (v_A, v_B) in H . Then for each arc (u, v) in G we add one arc (u_B, v_A) in H . Finally we set the attribute capacity = 1 for each arc in H .

This is equal to the local node connectivity because the value of a maximum s-t-flow is equal to the capacity of a minimum s-t-cut.

See also:

`local_edge_connectivity()`, `node_connectivity()`, `minimum_node_cut()`,
`maximum_flow()`, `edmonds_karp()`, `preflow_push()`, `shortest_augmenting_path()`

References

node_connectivity

node_connectivity ($G, s=None, t=None, flow_func=None$)

Returns node connectivity for a graph or digraph G .

Node connectivity is equal to the minimum number of nodes that must be removed to disconnect G or render it trivial. If source and target nodes are provided, this function returns the local node connectivity: the minimum number of nodes that must be removed to break all paths from source to target in G .

Parameters

- **G** (*NetworkX graph*) – Undirected graph
- **s** (*node*) – Source node. Optional. Default value: None.
- **t** (*node*) – Target node. Optional. Default value: None.
- **flow_func** (*function*) – A function for computing the maximum flow among a pair of nodes. The function has to accept at least three parameters: a Digraph, a source node, and a target node. And return a residual network that follows NetworkX conventions (see `maximum_flow()` for details). If `flow_func` is None, the default maximum flow function (`edmonds_karp()`) is used. See below for details. The choice of the default function may change from version to version and should not be relied on. Default value: None.

Returns **K** – Node connectivity of G , or local node connectivity if source and target are provided.

Return type integer

Examples

```
>>> # Platonic icosahedral graph is 5-node-connected
>>> G = nx.icosahedral_graph()
>>> nx.node_connectivity(G)
5
```

You can use alternative flow algorithms for the underlying maximum flow computation. In dense networks the algorithm `shortest_augmenting_path()` will usually perform better than the default `edmonds_karp()`, which is faster for sparse networks with highly skewed degree distributions. Alternative flow functions have to be explicitly imported from the flow package.

ological Foundations', Lecture Notes in Computer Science, Volume 3418, Springer-Verlag, 2005. http://www.informatik.uni-augsburg.de/thi/personen/kammer/Graph_Connectivity.pdf

```
>>> from networkx.algorithms.flow import shortest_augmenting_path
>>> nx.node_connectivity(G, flow_func=shortest_augmenting_path)
5
```

If you specify a pair of nodes (source and target) as parameters, this function returns the value of local node connectivity.

```
>>> nx.node_connectivity(G, 3, 7)
5
```

If you need to perform several local computations among different pairs of nodes on the same graph, it is recommended that you reuse the data structures used in the maximum flow computations. See `local_node_connectivity()` for details.

Notes

This is a flow based implementation of node connectivity. The algorithm works by solving $O((n - \delta - 1 + \delta(\delta - 1)/2))$ maximum flow problems on an auxiliary digraph. Where δ is the minimum degree of G . For details about the auxiliary digraph and the computation of local node connectivity see `local_node_connectivity()`. This implementation is based on algorithm 11 in ³⁵.

See also:

`local_node_connectivity()`, `edge_connectivity()`, `maximum_flow()`,
`edmonds_karp()`, `preflow_push()`, `shortest_augmenting_path()`

References

4.13.4 Flow-based Minimum Cuts

Flow based cut algorithms

<code>minimum_edge_cut(G[, s, t, flow_func])</code>	Returns a set of edges of minimum cardinality that disconnects G .
<code>minimum_node_cut(G[, s, t, flow_func])</code>	Returns a set of nodes of minimum cardinality that disconnects G .
<code>minimum_st_edge_cut(G, s, t[, flow_func, ...])</code>	Returns the edges of the cut-set of a minimum (s, t) -cut.
<code>minimum_st_node_cut(G, s, t[, flow_func, ...])</code>	Returns a set of nodes of minimum cardinality that disconnect source from target.

minimum_edge_cut

minimum_edge_cut ($G, s=None, t=None, flow_func=None$)

Returns a set of edges of minimum cardinality that disconnects G .

If source and target nodes are provided, this function returns the set of edges of minimum cardinality that, if removed, would break all paths among source and target in G . If not, it returns a set of edges of minimum cardinality that disconnects G .

Parameters

- **G** (*NetworkX graph*) –
- **s** (*node*) – Source node. Optional. Default value: None.
- **t** (*node*) – Target node. Optional. Default value: None.

³⁵ Abdol-Hossein Esfahanian. Connectivity Algorithms. http://www.cse.msu.edu/~cse835/Papers/Graph_connectivity_revised.pdf

- **flow_func** (function) – A function for computing the maximum flow among a pair of nodes. The function has to accept at least three parameters: a Digraph, a source node, and a target node. And return a residual network that follows NetworkX conventions (see `maximum_flow()` for details). If `flow_func` is `None`, the default maximum flow function (`edmonds_karp()`) is used. See below for details. The choice of the default function may change from version to version and should not be relied on. Default value: `None`.

Returns `cutset` – Set of edges that, if removed, would disconnect `G`. If source and target nodes are provided, the set contains the edges that if removed, would destroy all paths between source and target.

Return type `set`

Examples

```
>>> # Platonic icosahedral graph has edge connectivity 5
>>> G = nx.icosahedral_graph()
>>> len(nx.minimum_edge_cut(G))
5
```

You can use alternative flow algorithms for the underlying maximum flow computation. In dense networks the algorithm `shortest_augmenting_path()` will usually perform better than the default `edmonds_karp()`, which is faster for sparse networks with highly skewed degree distributions. Alternative flow functions have to be explicitly imported from the flow package.

```
>>> from networkx.algorithms.flow import shortest_augmenting_path
>>> len(nx.minimum_edge_cut(G, flow_func=shortest_augmenting_path))
5
```

If you specify a pair of nodes (source and target) as parameters, this function returns the value of local edge connectivity.

```
>>> nx.edge_connectivity(G, 3, 7)
5
```

If you need to perform several local computations among different pairs of nodes on the same graph, it is recommended that you reuse the data structures used in the maximum flow computations. See `local_edge_connectivity()` for details.

Notes

This is a flow based implementation of minimum edge cut. For undirected graphs the algorithm works by finding a ‘small’ dominating set of nodes of `G` (see algorithm 7 in ³⁶) and computing the maximum flow between an arbitrary node in the dominating set and the rest of nodes in it. This is an implementation of algorithm 6 in ¹. For directed graphs, the algorithm does `n` calls to the max flow function. It is an implementation of algorithm 8 in ¹.

See also:

`minimum_st_edge_cut()`, `minimum_node_cut()`, `stoer_wagner()`,
`node_connectivity()`, `edge_connectivity()`, `maximum_flow()`, `edmonds_karp()`,
`preflow_push()`, `shortest_augmenting_path()`

³⁶ Abdol-Hossein Esfahanian. Connectivity Algorithms. http://www.cse.msu.edu/~cse835/Papers/Graph_connectivity_revised.pdf

References

minimum_node_cut

minimum_node_cut (*G*, *s=None*, *t=None*, *flow_func=None*)

Returns a set of nodes of minimum cardinality that disconnects *G*.

If source and target nodes are provided, this function returns the set of nodes of minimum cardinality that, if removed, would destroy all paths among source and target in *G*. If not, it returns a set of nodes of minimum cardinality that disconnects *G*.

Parameters

- **G** (*NetworkX graph*) –
- **s** (*node*) – Source node. Optional. Default value: None.
- **t** (*node*) – Target node. Optional. Default value: None.
- **flow_func** (*function*) – A function for computing the maximum flow among a pair of nodes. The function has to accept at least three parameters: a Digraph, a source node, and a target node. And return a residual network that follows NetworkX conventions (see `maximum_flow()` for details). If `flow_func` is None, the default maximum flow function (`edmonds_karp()`) is used. See below for details. The choice of the default function may change from version to version and should not be relied on. Default value: None.

Returns **cutset** – Set of nodes that, if removed, would disconnect *G*. If source and target nodes are provided, the set contains the nodes that if removed, would destroy all paths between source and target.

Return type `set`

Examples

```
>>> # Platonic icosahedral graph has node connectivity 5
>>> G = nx.icosahedral_graph()
>>> node_cut = nx.minimum_node_cut(G)
>>> len(node_cut)
5
```

You can use alternative flow algorithms for the underlying maximum flow computation. In dense networks the algorithm `shortest_augmenting_path()` will usually perform better than the default `edmonds_karp()`, which is faster for sparse networks with highly skewed degree distributions. Alternative flow functions have to be explicitly imported from the flow package.

```
>>> from networkx.algorithms.flow import shortest_augmenting_path
>>> node_cut == nx.minimum_node_cut(G, flow_func=shortest_augmenting_path)
True
```

If you specify a pair of nodes (source and target) as parameters, this function returns a local st node cut.

```
>>> len(nx.minimum_node_cut(G, 3, 7))
5
```

If you need to perform several local st cuts among different pairs of nodes on the same graph, it is recommended that you reuse the data structures used in the maximum flow computations. See `minimum_st_node_cut()` for details.

Notes

This is a flow based implementation of minimum node cut. The algorithm is based in solving a number of maximum flow computations to determine the capacity of the minimum cut on an auxiliary directed network that corresponds to the minimum node cut of G . It handles both directed and undirected graphs. This implementation is based on algorithm 11 in ³⁷.

See also:

`minimum_st_node_cut()`, `minimum_cut()`, `minimum_edge_cut()`, `stoer_wagner()`, `node_connectivity()`, `edge_connectivity()`, `maximum_flow()`, `edmonds_karp()`, `preflow_push()`, `shortest_augmenting_path()`

References

minimum_st_edge_cut

minimum_st_edge_cut ($G, s, t, flow_func=None, auxiliary=None, residual=None$)

Returns the edges of the cut-set of a minimum (s, t) -cut.

This function returns the set of edges of minimum cardinality that, if removed, would destroy all paths among source and target in G . Edge weights are not considered

Parameters

- **G** (*NetworkX graph*) – Edges of the graph are expected to have an attribute called ‘capacity’. If this attribute is not present, the edge is considered to have infinite capacity.
- **s** (*node*) – Source node for the flow.
- **t** (*node*) – Sink node for the flow.
- **auxiliary** (*NetworkX DiGraph*) – Auxiliary digraph to compute flow based node connectivity. It has to have a graph attribute called mapping with a dictionary mapping node names in G and in the auxiliary digraph. If provided it will be reused instead of recreated. Default value: None.
- **flow_func** (*function*) – A function for computing the maximum flow among a pair of nodes. The function has to accept at least three parameters: a Digraph, a source node, and a target node. And return a residual network that follows NetworkX conventions (see `maximum_flow()` for details). If `flow_func` is None, the default maximum flow function (`edmonds_karp()`) is used. See `node_connectivity()` for details. The choice of the default function may change from version to version and should not be relied on. Default value: None.
- **residual** (*NetworkX DiGraph*) – Residual network to compute maximum flow. If provided it will be reused instead of recreated. Default value: None.

Returns **cutset** – Set of edges that, if removed from the graph, will disconnect it.

Return type `set`

See also:

`minimum_cut()`, `minimum_node_cut()`, `minimum_edge_cut()`, `stoer_wagner()`, `node_connectivity()`, `edge_connectivity()`, `maximum_flow()`, `edmonds_karp()`, `preflow_push()`, `shortest_augmenting_path()`

³⁷ Abdol-Hossein Esfahanian. Connectivity Algorithms. http://www.cse.msu.edu/~cse835/Papers/Graph_connectivity_revised.pdf

Examples

This function is not imported in the base NetworkX namespace, so you have to explicitly import it from the connectivity package:

```
>>> from networkx.algorithms.connectivity import minimum_st_edge_cut
```

We use in this example the platonic icosahedral graph, which has edge connectivity 5.

```
>>> G = nx.icosahedral_graph()
>>> len(minimum_st_edge_cut(G, 0, 6))
5
```

If you need to compute local edge cuts on several pairs of nodes in the same graph, it is recommended that you reuse the data structures that NetworkX uses in the computation: the auxiliary digraph for edge connectivity, and the residual network for the underlying maximum flow computation.

Example of how to compute local edge cuts among all pairs of nodes of the platonic icosahedral graph reusing the data structures.

```
>>> import itertools
>>> # You also have to explicitly import the function for
>>> # building the auxiliary digraph from the connectivity package
>>> from networkx.algorithms.connectivity import (
...     build_auxiliary_edge_connectivity)
>>> H = build_auxiliary_edge_connectivity(G)
>>> # And the function for building the residual network from the
>>> # flow package
>>> from networkx.algorithms.flow import build_residual_network
>>> # Note that the auxiliary digraph has an edge attribute named capacity
>>> R = build_residual_network(H, 'capacity')
>>> result = dict.fromkeys(G, dict())
>>> # Reuse the auxiliary digraph and the residual network by passing them
>>> # as parameters
>>> for u, v in itertools.combinations(G, 2):
...     k = len(minimum_st_edge_cut(G, u, v, auxiliary=H, residual=R))
...     result[u][v] = k
>>> all(result[u][v] == 5 for u, v in itertools.combinations(G, 2))
True
```

You can also use alternative flow algorithms for computing edge cuts. For instance, in dense networks the algorithm `shortest_augmenting_path()` will usually perform better than the default `edmonds_karp()` which is faster for sparse networks with highly skewed degree distributions. Alternative flow functions have to be explicitly imported from the flow package.

```
>>> from networkx.algorithms.flow import shortest_augmenting_path
>>> len(minimum_st_edge_cut(G, 0, 6, flow_func=shortest_augmenting_path))
5
```

minimum_st_node_cut

minimum_st_node_cut (*G, s, t, flow_func=None, auxiliary=None, residual=None*)

Returns a set of nodes of minimum cardinality that disconnect source from target in *G*.

This function returns the set of nodes of minimum cardinality that, if removed, would destroy all paths among source and target in *G*.

Parameters

- **G** (*NetworkX graph*) –
- **s** (*node*) – Source node.
- **t** (*node*) – Target node.
- **flow_func** (*function*) – A function for computing the maximum flow among a pair of nodes. The function has to accept at least three parameters: a Digraph, a source node, and a target node. And return a residual network that follows NetworkX conventions (see `maximum_flow()` for details). If `flow_func` is `None`, the default maximum flow function (`edmonds_karp()`) is used. See below for details. The choice of the default function may change from version to version and should not be relied on. Default value: `None`.
- **auxiliary** (*NetworkX DiGraph*) – Auxiliary digraph to compute flow based node connectivity. It has to have a graph attribute called `mapping` with a dictionary mapping node names in `G` and in the auxiliary digraph. If provided it will be reused instead of recreated. Default value: `None`.
- **residual** (*NetworkX DiGraph*) – Residual network to compute maximum flow. If provided it will be reused instead of recreated. Default value: `None`.

Returns `cutset` – Set of nodes that, if removed, would destroy all paths between source and target in `G`.

Return type `set`

Examples

This function is not imported in the base NetworkX namespace, so you have to explicitly import it from the connectivity package:

```
>>> from networkx.algorithms.connectivity import minimum_st_node_cut
```

We use in this example the platonic icosahedral graph, which has node connectivity 5.

```
>>> G = nx.icosahedral_graph()
>>> len(minimum_st_node_cut(G, 0, 6))
5
```

If you need to compute local st cuts between several pairs of nodes in the same graph, it is recommended that you reuse the data structures that NetworkX uses in the computation: the auxiliary digraph for node connectivity and node cuts, and the residual network for the underlying maximum flow computation.

Example of how to compute local st node cuts reusing the data structures:

```
>>> # You also have to explicitly import the function for
>>> # building the auxiliary digraph from the connectivity package
>>> from networkx.algorithms.connectivity import (
...     build_auxiliary_node_connectivity)
>>> H = build_auxiliary_node_connectivity(G)
>>> # And the function for building the residual network from the
>>> # flow package
>>> from networkx.algorithms.flow import build_residual_network
>>> # Note that the auxiliary digraph has an edge attribute named capacity
>>> R = build_residual_network(H, 'capacity')
>>> # Reuse the auxiliary digraph and the residual network by passing them
>>> # as parameters
>>> len(minimum_st_node_cut(G, 0, 6, auxiliary=H, residual=R))
5
```


You can also use alternative flow algorithms for computing minimum st node cuts. For instance, in dense networks the algorithm `shortest_augmenting_path()` will usually perform better than the default `edmonds_karp()` which is faster for sparse networks with highly skewed degree distributions. Alternative flow functions have to be explicitly imported from the flow package.

```
>>> from networkx.algorithms.flow import shortest_augmenting_path
>>> len(minimum_st_node_cut(G, 0, 6, flow_func=shortest_augmenting_path))
5
```

Notes

This is a flow based implementation of minimum node cut. The algorithm is based in solving a number of maximum flow computations to determine the capacity of the minimum cut on an auxiliary directed network that corresponds to the minimum node cut of G . It handles both directed and undirected graphs. This implementation is based on algorithm 11 in ³⁸.

See also:

`minimum_node_cut()`, `minimum_edge_cut()`, `stoer_wagner()`, `node_connectivity()`, `edge_connectivity()`, `maximum_flow()`, `edmonds_karp()`, `preflow_push()`, `shortest_augmenting_path()`

References

4.13.5 Stoer-Wagner minimum cut

Stoer-Wagner minimum cut algorithm.

`stoer_wagner(G[, weight, heap])` Returns the weighted minimum edge cut using the Stoer-Wagner algorithm.

stoer_wagner

stoer_wagner (G , *weight*='weight', *heap*=<class 'networkx.utils.heaps.BinaryHeap'>)

Returns the weighted minimum edge cut using the Stoer-Wagner algorithm.

Determine the minimum edge cut of a connected graph using the Stoer-Wagner algorithm. In weighted cases, all weights must be nonnegative.

The running time of the algorithm depends on the type of heaps used:

Type of heap	Running time
Binary heap	$O(n(m+n)\log n)$
Fibonacci heap	$O(nm + n^2\log n)$
Pairing heap	$O(2^{2\sqrt{\log \log n}}nm + n^2\log n)$

Parameters

- **G** (*NetworkX graph*) – Edges of the graph are expected to have an attribute named by the *weight* parameter below. If this attribute is not present, the edge is considered to have unit weight.

³⁸ Abdol-Hossein Esfahanian. Connectivity Algorithms. http://www.cse.msu.edu/~cse835/Papers/Graph_connectivity_revised.pdf

- **weight** (*string*) – Name of the weight attribute of the edges. If the attribute is not present, unit weight is assumed. Default value: ‘weight’.
- **heap** (*class*) – Type of heap to be used in the algorithm. It should be a subclass of `MinHeap` or implement a compatible interface.

If a stock heap implementation is to be used, `BinaryHeap` is recommended over `PairingHeap` for Python implementations without optimized attribute accesses (e.g., CPython) despite a slower asymptotic running time. For Python implementations with optimized attribute accesses (e.g., PyPy), `PairingHeap` provides better performance. Default value: `BinaryHeap`.

Returns

- **cut_value** (*integer or float*) – The sum of weights of edges in a minimum cut.
- **partition** (*pair of node lists*) – A partitioning of the nodes that defines a minimum cut.

Raises

- `NetworkXNotImplemented` – If the graph is directed or a multigraph.
- `NetworkXError` – If the graph has less than two nodes, is not connected or has a negative-weighted edge.

Examples

```
>>> G = nx.Graph()
>>> G.add_edge('x', 'a', weight=3)
>>> G.add_edge('x', 'b', weight=1)
>>> G.add_edge('a', 'c', weight=3)
>>> G.add_edge('b', 'c', weight=5)
>>> G.add_edge('b', 'd', weight=4)
>>> G.add_edge('d', 'e', weight=2)
>>> G.add_edge('c', 'y', weight=2)
>>> G.add_edge('e', 'y', weight=3)
>>> cut_value, partition = nx.stoer_wagner(G)
>>> cut_value
4
```

4.13.6 Utils for flow-based connectivity

Utilities for connectivity package

<code>build_auxiliary_edge_connectivity(G)</code>	Auxiliary digraph for computing flow based edge connectivity
<code>build_auxiliary_node_connectivity(G)</code>	Creates a directed graph D from an undirected graph G to compute flow based

`build_auxiliary_edge_connectivity`

`build_auxiliary_edge_connectivity(G)`

Auxiliary digraph for computing flow based edge connectivity

If the input graph is undirected, we replace each edge (u, v) with two reciprocal arcs (u, v) and (v, u) and then we set the attribute ‘capacity’ for each arc to 1. If the input graph is directed we simply add the ‘capacity’ attribute. Part of algorithm 1 in ³⁹.

³⁹ Abdol-Hossein Esfahanian. Connectivity Algorithms. (this is a chapter, look for the reference of the book).

References

build_auxiliary_node_connectivity

build_auxiliary_node_connectivity(*G*)

Creates a directed graph *D* from an undirected graph *G* to compute flow based node connectivity.

For an undirected graph *G* having n nodes and m edges we derive a directed graph *D* with $2n$ nodes and $2m + n$ arcs by replacing each original node v with two nodes vA, vB linked by an (internal) arc in *D*. Then for each edge (u, v) in *G* we add two arcs (uB, vA) and (vB, uA) in *D*. Finally we set the attribute capacity = 1 for each arc in *D*⁴⁰.

For a directed graph having n nodes and m arcs we derive a directed graph *D* with $2n$ nodes and $m + n$ arcs by replacing each original node v with two nodes vA, vB linked by an (internal) arc (vA, vB) in *D*. Then for each arc (u, v) in *G* we add one arc (uB, vA) in *D*. Finally we set the attribute capacity = 1 for each arc in *D*.

A dictionary with a mapping between nodes in the original graph and the auxiliary digraph is stored as a graph attribute: `H.graph['mapping']`.

References

4.14 Cores

Find the k-cores of a graph.

The k-core is found by recursively pruning nodes with degrees less than k.

See the following reference for details:

An O(m) Algorithm for Cores Decomposition of Networks Vladimir Batagelj and Matjaz Zaversnik, 2003.
<http://arxiv.org/abs/cs.DS/0310049>

<code>core_number(G)</code>	Return the core number for each vertex.
<code>k_core(G[, k, core_number])</code>	Return the k-core of G.
<code>k_shell(G[, k, core_number])</code>	Return the k-shell of G.
<code>k_crust(G[, k, core_number])</code>	Return the k-crust of G.
<code>k_corona(G, k[, core_number])</code>	Return the k-corona of G.

4.14.1 core_number

core_number(*G*)

Return the core number for each vertex.

A k-core is a maximal subgraph that contains nodes of degree k or more.

The core number of a node is the largest value k of a k-core containing that node.

Parameters *G* (*NetworkX graph*) – A graph or directed graph

Returns `core_number` – A dictionary keyed by node to the core number.

http://www.cse.msu.edu/~cse835/Papers/Graph_connectivity_revised.pdf

⁴⁰ Kammer, Frank and Hanjo Taubig. Graph Connectivity. in Brandes and Erlebach, 'Network Analysis: Methodological Foundations', Lecture Notes in Computer Science, Volume 3418, Springer-Verlag, 2005. http://www.informatik.uni-augsburg.de/thi/personen/kammer/Graph_Connectivity.pdf

Return type dictionary

Raises `NetworkXError` – The k-core is not defined for graphs with self loops or parallel edges.

Notes

Not implemented for graphs with parallel edges or self loops.

For directed graphs the node degree is defined to be the in-degree + out-degree.

References

4.14.2 `k_core`

`k_core` (*G*, *k=None*, *core_number=None*)

Return the k-core of G.

A k-core is a maximal subgraph that contains nodes of degree k or more.

Parameters

- **G** (*NetworkX graph*) – A graph or directed graph
- **k** (*int, optional*) – The order of the core. If not specified return the main core.
- **core_number** (*dictionary, optional*) – Precomputed core numbers for the graph G.

Returns **G** – The k-core subgraph

Return type `NetworkX graph`

Raises `NetworkXError` – The k-core is not defined for graphs with self loops or parallel edges.

Notes

The main core is the core with the largest degree.

Not implemented for graphs with parallel edges or self loops.

For directed graphs the node degree is defined to be the in-degree + out-degree.

Graph, node, and edge attributes are copied to the subgraph.

See also:

`core_number()`

References

4.14.3 `k_shell`

`k_shell` (*G*, *k=None*, *core_number=None*)

Return the k-shell of G.

The k-shell is the subgraph of nodes in the k-core but not in the (k+1)-core.

Parameters

- **G** (*NetworkX graph*) – A graph or directed graph.

- **k** (*int, optional*) – The order of the shell. If not specified return the main shell.
- **core_number** (*dictionary, optional*) – Precomputed core numbers for the graph G.

Returns G – The k-shell subgraph

Return type NetworkX graph

Raises NetworkXError – The k-shell is not defined for graphs with self loops or parallel edges.

Notes

This is similar to `k_corona` but in that case only neighbors in the k-core are considered.

Not implemented for graphs with parallel edges or self loops.

For directed graphs the node degree is defined to be the in-degree + out-degree.

Graph, node, and edge attributes are copied to the subgraph.

See also:

`core_number()`, `k_corona()`

References

4.14.4 k_crust

k_crust (G, k=None, core_number=None)

Return the k-crust of G.

The k-crust is the graph G with the k-core removed.

Parameters

- **G** (*NetworkX graph*) – A graph or directed graph.
- **k** (*int, optional*) – The order of the shell. If not specified return the main crust.
- **core_number** (*dictionary, optional*) – Precomputed core numbers for the graph G.

Returns G – The k-crust subgraph

Return type NetworkX graph

Raises NetworkXError – The k-crust is not defined for graphs with self loops or parallel edges.

Notes

This definition of k-crust is different than the definition in ⁴¹. The k-crust in ¹ is equivalent to the k+1 crust of this algorithm.

Not implemented for graphs with parallel edges or self loops.

For directed graphs the node degree is defined to be the in-degree + out-degree.

Graph, node, and edge attributes are copied to the subgraph.

See also:

⁴¹ A model of Internet topology using k-shell decomposition Shai Carmi, Shlomo Havlin, Scott Kirkpatrick, Yuval Shavitt, and Eran Shir, PNAS July 3, 2007 vol. 104 no. 27 11150-11154 <http://www.pnas.org/content/104/27/11150.full>

`core_number()`

References

4.14.5 k_corona

k_corona(*G*, *k*, *core_number=None*)

Return the k-corona of *G*.

The k-corona is the subgraph of nodes in the k-core which have exactly *k* neighbours in the k-core.

Parameters

- **G** (*NetworkX graph*) – A graph or directed graph
- **k** (*int*) – The order of the corona.
- **core_number** (*dictionary, optional*) – Precomputed core numbers for the graph *G*.

Returns **G** – The k-corona subgraph

Return type NetworkX graph

Raises `NetworkXError` – The k-corona is not defined for graphs with self loops or parallel edges.

Notes

Not implemented for graphs with parallel edges or self loops.

For directed graphs the node degree is defined to be the in-degree + out-degree.

Graph, node, and edge attributes are copied to the subgraph.

See also:

`core_number()`

References

4.15 Cycles

4.15.1 Cycle finding algorithms

<code>cycle_basis(G[, root])</code>	Returns a list of cycles which form a basis for cycles of <i>G</i> .
<code>simple_cycles(G)</code>	Find simple cycles (elementary circuits) of a directed graph.
<code>find_cycle(G[, source, orientation])</code>	Returns the edges of a cycle found via a directed, depth-first traversal.

4.15.2 cycle_basis

cycle_basis(*G*, *root=None*)

Returns a list of cycles which form a basis for cycles of *G*.

A basis for cycles of a network is a minimal collection of cycles such that any cycle in the network can be written as a sum of cycles in the basis. Here summation of cycles is defined as “exclusive or” of the edges. Cycle bases are useful, e.g. when deriving equations for electric circuits using Kirchhoff’s Laws.

Parameters

- **G** (*NetworkX Graph*) –
- **root** (*node, optional*) – Specify starting node for basis.

Returns

- *A list of cycle lists. Each cycle list is a list of nodes*
- *which forms a cycle (loop) in G.*

Examples

```
>>> G=nx.Graph()
>>> G.add_cycle([0,1,2,3])
>>> G.add_cycle([0,3,4,5])
>>> print(nx.cycle_basis(G,0))
[[3, 4, 5, 0], [1, 2, 3, 0]]
```

Notes

This is adapted from algorithm CACM 491 ⁴².

References

See also:

`simple_cycles()`

4.15.3 simple_cycles

simple_cycles(G)

Find simple cycles (elementary circuits) of a directed graph.

An simple cycle, or elementary circuit, is a closed path where no node appears twice, except that the first and last node are the same. Two elementary circuits are distinct if they are not cyclic permutations of each other.

This is a nonrecursive, iterator/generator version of Johnson's algorithm ⁴³. There may be better algorithms for some cases ^{44 45}.

Parameters **G** (*NetworkX DiGraph*) – A directed graph

Returns **cycle_generator** – A generator that produces elementary cycles of the graph. Each cycle is a list of nodes with the first and last nodes being the same.

Return type generator

⁴² Paton, K. An algorithm for finding a fundamental set of cycles of a graph. Comm. ACM 12, 9 (Sept 1969), 514-518.

⁴³ Finding all the elementary circuits of a directed graph. D. B. Johnson, SIAM Journal on Computing 4, no. 1, 77-84, 1975. <http://dx.doi.org/10.1137/0204007>

⁴⁴ Enumerating the cycles of a digraph: a new preprocessing strategy. G. Loizou and P. Thanish, Information Sciences, v. 27, 163-182, 1982.

⁴⁵ A search strategy for the elementary cycles of a directed graph. J.L. Szwarcfiter and P.E. Lauer, BIT NUMERICAL MATHEMATICS, v. 16, no. 2, 192-204, 1976.

Examples

```
>>> G = nx.DiGraph([(0, 0), (0, 1), (0, 2), (1, 2), (2, 0), (2, 1), (2, 2)])
>>> len(list(nx.simple_cycles(G)))
5
```

To filter the cycles so that they don't include certain nodes or edges, copy your graph and eliminate those nodes or edges before calling

```
>>> copyG = G.copy()
>>> copyG.remove_nodes_from([1])
>>> copyG.remove_edges_from([(0, 1)])
>>> len(list(nx.simple_cycles(copyG)))
3
```

Notes

The implementation follows pp. 79-80 in ¹.

The time complexity is $O((n + e)(c + 1))$ for n nodes, e edges and c elementary circuits.

References

See also:

`cycle_basis()`

4.15.4 find_cycle

find_cycle(*G*, *source=None*, *orientation='original'*)

Returns the edges of a cycle found via a directed, depth-first traversal.

Parameters

- **G** (*graph*) – A directed/undirected graph/multigraph.
- **source** (*node*, *list of nodes*) – The node from which the traversal begins. If `None`, then a source is chosen arbitrarily and repeatedly until all edges from each node in the graph are searched.
- **orientation** (*'original' | 'reverse' | 'ignore'*) – For directed graphs and directed multigraphs, edge traversals need not respect the original orientation of the edges. When set to `'reverse'`, then every edge will be traversed in the reverse direction. When set to `'ignore'`, then each directed edge is treated as a single undirected edge that can be traversed in either direction. For undirected graphs and undirected multigraphs, this parameter is meaningless and is not consulted by the algorithm.

Returns **edges** – A list of directed edges indicating the path taken for the loop. If no cycle is found, then **edges** will be an empty list. For graphs, an edge is of the form (u, v) where u and v are the tail and head of the edge as determined by the traversal. For multigraphs, an edge is of the form (u, v, key) , where **key** is the key of the edge. When the graph is directed, then u and v are always in the order of the actual directed edge. If orientation is `'ignore'`, then an edge takes the form $(u, v, \text{key}, \text{direction})$ where **direction** indicates if the edge was followed in the forward (tail to head) or reverse (head to tail) direction. When the direction is forward, the value of **direction** is `'forward'`. When the direction is reverse, the value of **direction** is `'reverse'`.

Return type directed edges

Examples

In this example, we construct a DAG and find, in the first call, that there are no directed cycles, and so an exception is raised. In the second call, we ignore edge orientations and find that there is an undirected cycle. Note that the second call finds a directed cycle while effectively traversing an undirected graph, and so, we found an “undirected cycle”. This means that this DAG structure does not form a directed tree (which is also known as a polytree).

```
>>> import networkx as nx
>>> G = nx.DiGraph([(0,1), (0,2), (1,2)])
>>> try:
...     find_cycle(G, orientation='original')
... except:
...     pass
...
>>> list(find_cycle(G, orientation='ignore'))
[(0, 1, 'forward'), (1, 2, 'forward'), (0, 2, 'reverse')]
```

4.16 Directed Acyclic Graphs

<code>ancestors(G, source)</code>	Return all nodes having a path to <i>source</i> in G.
<code>descendants(G, source)</code>	Return all nodes reachable from <i>source</i> in G.
<code>topological_sort(G[, nbunch, reverse])</code>	Return a list of nodes in topological sort order.
<code>topological_sort_recursive(G[, nbunch, reverse])</code>	Return a list of nodes in topological sort order.
<code>is_directed_acyclic_graph(G)</code>	Return True if the graph G is a directed acyclic graph (DAG) or False
<code>is_aperiodic(G)</code>	Return True if G is aperiodic.
<code>transitive_closure(G)</code>	Returns transitive closure of a directed graph
<code>antichains(G)</code>	Generates antichains from a DAG.
<code>dag_longest_path(G)</code>	Returns the longest path in a DAG
<code>dag_longest_path_length(G)</code>	Returns the longest path length in a DAG

4.16.1 ancestors

ancestors (*G, source*)

Return all nodes having a path to *source* in G.

Parameters

- **G** (*NetworkX DiGraph*) –
- **source** (*node in G*) –

Returns **ancestors** – The ancestors of source in G

Return type set()

4.16.2 descendants

descendants (*G, source*)

Return all nodes reachable from *source* in G.

Parameters

- **G** (*NetworkX DiGraph*) –
- **source** (*node in G*) –

Returns **des** – The descendants of source in G

Return type `set()`

4.16.3 `topological_sort`

topological_sort (*G, nbunch=None, reverse=False*)

Return a list of nodes in topological sort order.

A topological sort is a nonunique permutation of the nodes such that an edge from u to v implies that u appears before v in the topological sort order.

Parameters

- **G** (*NetworkX digraph*) – A directed graph
- **nbunch** (*container of nodes (optional)*) – Explore graph in specified order given in nbunch
- **reverse** (*bool, optional*) – Return postorder instead of preorder if True. Reverse mode is a bit more efficient.

Raises

- `NetworkXError` – Topological sort is defined for directed graphs only. If the graph G is undirected, a `NetworkXError` is raised.
- `NetworkXUnfeasible` – If G is not a directed acyclic graph (DAG) no topological sort exists and a `NetworkXUnfeasible` exception is raised.

Notes

This algorithm is based on a description and proof in The Algorithm Design Manual ⁴⁶.

See also:

`is_directed_acyclic_graph()`

References

4.16.4 `topological_sort_recursive`

topological_sort_recursive (*G, nbunch=None, reverse=False*)

Return a list of nodes in topological sort order.

A topological sort is a nonunique permutation of the nodes such that an edge from u to v implies that u appears before v in the topological sort order.

Parameters

- **G** (*NetworkX digraph*) –
- **nbunch** (*container of nodes (optional)*) – Explore graph in specified order given in nbunch

⁴⁶ Skiena, S. S. The Algorithm Design Manual (Springer-Verlag, 1998). http://www.amazon.com/exec/obidos/ASIN/0387948600/ref=ase_thealgorithmrepo/

- **reverse** (*bool, optional*) – Return postorder instead of preorder if True. Reverse mode is a bit more efficient.

Raises

- `NetworkXError` – Topological sort is defined for directed graphs only. If the graph `G` is undirected, a `NetworkXError` is raised.
- `NetworkXUnfeasible` – If `G` is not a directed acyclic graph (DAG) no topological sort exists and a `NetworkXUnfeasible` exception is raised.

Notes

This is a recursive version of topological sort.

See also:

`topological_sort()`, `is_directed_acyclic_graph()`

4.16.5 `is_directed_acyclic_graph`

`is_directed_acyclic_graph(G)`

Return True if the graph `G` is a directed acyclic graph (DAG) or False if not.

Parameters `G` (*NetworkX graph*) – A graph

Returns `is_dag` – True if `G` is a DAG, false otherwise

Return type `bool`

4.16.6 `is_aperiodic`

`is_aperiodic(G)`

Return True if `G` is aperiodic.

A directed graph is aperiodic if there is no integer $k > 1$ that divides the length of every cycle in the graph.

Parameters `G` (*NetworkX DiGraph*) – Graph

Returns `aperiodic` – True if the graph is aperiodic False otherwise

Return type `boolean`

Raises `NetworkXError` – If `G` is not directed

Notes

This uses the method outlined in ⁴⁷, which runs in $O(m)$ time given m edges in `G`. Note that a graph is not aperiodic if it is acyclic as every integer trivially divides length 0 cycles.

⁴⁷ Jarvis, J. P.; Shier, D. R. (1996), Graph-theoretic analysis of finite Markov chains, in Shier, D. R.; Wallenius, K. T., Applied Mathematical Modeling: A Multidisciplinary Approach, CRC Press.

References

4.16.7 transitive_closure

transitive_closure(*G*)

Returns transitive closure of a directed graph

The transitive closure of $G = (V, E)$ is a graph $G+ = (V, E+)$ such that for all v, w in V there is an edge (v, w) in $E+$ if and only if there is a non-null path from v to w in G .

Parameters *G* (*NetworkX DiGraph*) – Graph

Returns *TC* – Graph

Return type *NetworkX DiGraph*

Raises *NetworkXNotImplemented* – If *G* is not directed

References

4.16.8 antichains

antichains(*G*)

Generates antichains from a DAG.

An antichain is a subset of a partially ordered set such that any two elements in the subset are incomparable.

Parameters *G* (*NetworkX DiGraph*) – Graph

Returns *antichain*

Return type generator object

Raises

- *NetworkXNotImplemented* – If *G* is not directed
- *NetworkXUnfeasible* – If *G* contains a cycle

Notes

This function was originally developed by Peter Jipsen and Franco Saliola for the SAGE project. It's included in NetworkX with permission from the authors. Original SAGE code at:

https://sage.informatik.uni-goettingen.de/src/combinat/posets/hasse_diagram.py

References

4.16.9 dag_longest_path

dag_longest_path(*G*)

Returns the longest path in a DAG

Parameters *G* (*NetworkX DiGraph*) – Graph

Returns *path* – Longest path

Return type *list*

Raises `NetworkXNotImplemented` – If `G` is not directed

See also:

`dag_longest_path_length()`

4.16.10 `dag_longest_path_length`

`dag_longest_path_length`(`G`)

Returns the longest path length in a DAG

Parameters `G` (*NetworkX DiGraph*) – Graph

Returns `path_length` – Longest path length

Return type `int`

Raises `NetworkXNotImplemented` – If `G` is not directed

See also:

`dag_longest_path()`

4.17 Distance Measures

Graph diameter, radius, eccentricity and other properties.

<code>center</code> (<code>G</code> , <code>e</code>)	Return the center of the graph <code>G</code> .
<code>diameter</code> (<code>G</code> , <code>e</code>)	Return the diameter of the graph <code>G</code> .
<code>eccentricity</code> (<code>G</code> , <code>v</code> , <code>sp</code>)	Return the eccentricity of nodes in <code>G</code> .
<code>periphery</code> (<code>G</code> , <code>e</code>)	Return the periphery of the graph <code>G</code> .
<code>radius</code> (<code>G</code> , <code>e</code>)	Return the radius of the graph <code>G</code> .

4.17.1 `center`

`center`(`G`, `e=None`)

Return the center of the graph `G`.

The center is the set of nodes with eccentricity equal to radius.

Parameters

- `G` (*NetworkX graph*) – A graph
- `e` (*eccentricity dictionary, optional*) – A precomputed dictionary of eccentricities.

Returns `c` – List of nodes in center

Return type `list`

4.17.2 `diameter`

`diameter`(`G`, `e=None`)

Return the diameter of the graph `G`.

The diameter is the maximum eccentricity.

Parameters

- **G** (*NetworkX graph*) – A graph
- **e** (*eccentricity dictionary, optional*) – A precomputed dictionary of eccentricities.

Returns **d** – Diameter of graph

Return type integer

See also:

`eccentricity()`

4.17.3 eccentricity

eccentricity (*G, v=None, sp=None*)

Return the eccentricity of nodes in G.

The eccentricity of a node *v* is the maximum distance from *v* to all other nodes in G.

Parameters

- **G** (*NetworkX graph*) – A graph
- **v** (*node, optional*) – Return value of specified node
- **sp** (*dict of dicts, optional*) – All pairs shortest path lengths as a dictionary of dictionaries

Returns **ecc** – A dictionary of eccentricity values keyed by node.

Return type dictionary

4.17.4 periphery

periphery (*G, e=None*)

Return the periphery of the graph G.

The periphery is the set of nodes with eccentricity equal to the diameter.

Parameters

- **G** (*NetworkX graph*) – A graph
- **e** (*eccentricity dictionary, optional*) – A precomputed dictionary of eccentricities.

Returns **p** – List of nodes in periphery

Return type list

4.17.5 radius

radius (*G, e=None*)

Return the radius of the graph G.

The radius is the minimum eccentricity.

Parameters

- **G** (*NetworkX graph*) – A graph
- **e** (*eccentricity dictionary, optional*) – A precomputed dictionary of eccentricities.

Returns *r* – Radius of graph

Return type integer

4.18 Distance-Regular Graphs

4.18.1 Distance-regular graphs

<code>is_distance_regular(G)</code>	Returns True if the graph is distance regular, False otherwise.
<code>intersection_array(G)</code>	Returns the intersection array of a distance-regular graph.
<code>global_parameters(b, c)</code>	Return global parameters for a given intersection array.

4.18.2 `is_distance_regular`

`is_distance_regular(G)`

Returns True if the graph is distance regular, False otherwise.

A connected graph *G* is distance-regular if for any nodes *x,y* and any integers *i,j=0,1,...,d* (where *d* is the graph diameter), the number of vertices at distance *i* from *x* and distance *j* from *y* depends only on *i,j* and the graph distance between *x* and *y*, independently of the choice of *x* and *y*.

Parameters *G* (*Networkx graph (undirected)*) –

Returns True if the graph is Distance Regular, False otherwise

Return type bool

Examples

```
>>> G=nx.hypercube_graph(6)
>>> nx.is_distance_regular(G)
True
```

See also:

`intersection_array()`, `global_parameters()`

Notes

For undirected and simple graphs only

References

4.18.3 `intersection_array`

`intersection_array(G)`

Returns the intersection array of a distance-regular graph.

Given a distance-regular graph *G* with integers *b_i, c_i, i = 0,...,d* such that for any 2 vertices *x,y* in *G* at a distance *i=d(x,y)*, there are exactly *c_i* neighbors of *y* at a distance of *i-1* from *x* and *b_i* neighbors of *y* at a distance of *i+1* from *x*.

A distance regular graph's intersection array is given by, $[b_0, b_1, \dots, b_{d-1}; c_1, c_2, \dots, c_d]$

Parameters *G* (*Networkx graph (undirected)*) –

Returns *b, c*

Return type tuple of lists

Examples

```
>>> G=nx.icosahedral_graph()
>>> nx.intersection_array(G)
([5, 2, 1], [1, 2, 5])
```

References

See also:

`global_parameters()`

4.18.4 global_parameters

global_parameters (*b, c*)

Return global parameters for a given intersection array.

Given a distance-regular graph *G* with integers $b_i, c_i, i = 0, \dots, d$ such that for any 2 vertices *x, y* in *G* at a distance $i = d(x, y)$, there are exactly c_i neighbors of *y* at a distance of $i-1$ from *x* and b_i neighbors of *y* at a distance of $i+1$ from *x*.

Thus, a distance regular graph has the global parameters, $[[c_0, a_0, b_0], [c_1, a_1, b_1], \dots, [c_d, a_d, b_d]]$ for the intersection array $[b_0, b_1, \dots, b_{d-1}; c_1, c_2, \dots, c_d]$ where $a_i + b_i + c_i = k$, $k =$ degree of every vertex.

Parameters *b, c* (*tuple of lists*) –

Returns *p*

Return type list of three-tuples

Examples

```
>>> G=nx.dodecahedral_graph()
>>> b,c=nx.intersection_array(G)
>>> list(nx.global_parameters(b,c))
[(0, 0, 3), (1, 0, 2), (1, 1, 1), (1, 1, 1), (2, 0, 1), (3, 0, 0)]
```

References

See also:

`intersection_array()`

4.19 Dominance

Dominance algorithms.

<code>immediate_dominators(G, start)</code>	Returns the immediate dominators of all nodes of a directed graph.
<code>dominance_frontiers(G, start)</code>	Returns the dominance frontiers of all nodes of a directed graph.

4.19.1 immediate_dominators

immediate_dominators(*G*, *start*)

Returns the immediate dominators of all nodes of a directed graph.

Parameters

- **G** (*a DiGraph or MultiDiGraph*) – The graph where dominance is to be computed.
- **start** (*node*) – The start node of dominance computation.

Returns idom – A dict containing the immediate dominators of each node reachable from *start*.

Return type dict keyed by nodes

Raises

- `NetworkXNotImplemented` – If *G* is undirected.
- `NetworkXError` – If *start* is not in *G*.

Notes

Except for *start*, the immediate dominators are the parents of their corresponding nodes in the dominator tree.

Examples

```
>>> G = nx.DiGraph([(1, 2), (1, 3), (2, 5), (3, 4), (4, 5)])
>>> sorted(nx.immediate_dominators(G, 1).items())
[(1, 1), (2, 1), (3, 1), (4, 3), (5, 1)]
```

References

4.19.2 dominance_frontiers

dominance_frontiers(*G*, *start*)

Returns the dominance frontiers of all nodes of a directed graph.

Parameters

- **G** (*a DiGraph or MultiDiGraph*) – The graph where dominance is to be computed.
- **start** (*node*) – The start node of dominance computation.

Returns df – A dict containing the dominance frontiers of each node reachable from *start* as lists.

Return type dict keyed by nodes

Raises

- `NetworkXNotImplemented` – If G is undirected.
- `NetworkXError` – If `start` is not in G .

Examples

```
>>> G = nx.DiGraph([(1, 2), (1, 3), (2, 5), (3, 4), (4, 5)])
>>> sorted((u, sorted(df)) for u, df in nx.dominance_frontiers(G, 1).items())
[(1, []), (2, [5]), (3, [5]), (4, [5]), (5, [])]
```

References

4.20 Dominating Sets

<code>dominating_set(G[, start_with])</code>	Finds a dominating set for the graph G .
<code>is_dominating_set(G, nbunch)</code>	Checks if nodes in <code>nbunch</code> are a dominating set for G .

4.20.1 dominating_set

dominating_set (G , *start_with=None*)

Finds a dominating set for the graph G .

A dominating set for a graph $G = (V, E)$ is a node subset D of V such that every node not in D is adjacent to at least one member of D ⁴⁸.

Parameters

- **G** (*NetworkX graph*) –
- **start_with** (*Node (default=None)*) – Node to use as a starting point for the algorithm.

Returns **D** – A dominating set for G .

Return type `set`

Notes

This function is an implementation of algorithm 7 in ⁴⁹ which finds some dominating set, not necessarily the smallest one.

See also:

`is_dominating_set()`

References

4.20.2 is_dominating_set

is_dominating_set (G , *nbunch*)

Checks if nodes in `nbunch` are a dominating set for G .

⁴⁸ http://en.wikipedia.org/wiki/Dominating_set

⁴⁹ Abdol-Hossein Esfahanian. Connectivity Algorithms. http://www.cse.msu.edu/~cse835/Papers/Graph_connectivity_revised.pdf

A dominating set for a graph $G = (V, E)$ is a node subset D of V such that every node not in D is adjacent to at least one member of D ⁵⁰.

Parameters

- **G** (*NetworkX graph*) –
- **nbunch** (*Node container*) –

See also:

`dominating_set()`

References

4.21 Eulerian

Eulerian circuits and graphs.

<code>is_eulerian(G)</code>	Return True if G is an Eulerian graph, False otherwise.
<code>eulerian_circuit(G[, source])</code>	Return the edges of an Eulerian circuit in G.

4.21.1 is_eulerian

is_eulerian (*G*)

Return True if G is an Eulerian graph, False otherwise.

An Eulerian graph is a graph with an Eulerian circuit.

Parameters **G** (*graph*) – A NetworkX Graph

Examples

```
>>> nx.is_eulerian(nx.DiGraph({0:[3], 1:[2], 2:[3], 3:[0, 1]}))
True
>>> nx.is_eulerian(nx.complete_graph(5))
True
>>> nx.is_eulerian(nx.petersen_graph())
False
```

Notes

This implementation requires the graph to be connected (or strongly connected for directed graphs).

4.21.2 eulerian_circuit

eulerian_circuit (*G, source=None*)

Return the edges of an Eulerian circuit in G.

An Eulerian circuit is a path that crosses every edge in G exactly once and finishes at the starting node.

⁵⁰ http://en.wikipedia.org/wiki/Dominating_set

Parameters

- **G** (*NetworkX Graph or DiGraph*) – A directed or undirected graph
- **source** (*node, optional*) – Starting node for circuit.

Returns **edges** – A generator that produces edges in the Eulerian circuit.

Return type generator

Raises `NetworkXError` – If the graph is not Eulerian.

See also:

`is_eulerian()`

Notes

Linear time algorithm, adapted from ⁵¹. General information about Euler tours ⁵².

References**Examples**

```
>>> G=nx.complete_graph(3)
>>> list(nx.eulerian_circuit(G))
[(0, 2), (2, 1), (1, 0)]
>>> list(nx.eulerian_circuit(G,source=1))
[(1, 2), (2, 0), (0, 1)]
>>> [u for u,v in nx.eulerian_circuit(G)] # nodes in circuit
[0, 2, 1]
```

4.22 Flows

4.22.1 Maximum Flow

4.22.2 Edmonds-Karp

4.22.3 Shortest Augmenting Path

4.22.4 Preflow-Push

⁵¹ J. Edmonds, E. L. Johnson. Matching, Euler tours and the Chinese postman. Mathematical programming, Volume 5, Issue 1 (1973), 111-114.

⁵² http://en.wikipedia.org/wiki/Eulerian_path

4.22.5 Utils

4.22.6 Network Simplex

4.22.7 Capacity Scaling Minimum Cost Flow

4.23 Graphical degree sequence

Test sequences for graphiness.

<code>is_graphical(sequence[, method])</code>	Returns True if sequence is a valid degree sequence.
<code>is_digraphical(in_sequence, out_sequence)</code>	Returns True if some directed graph can realize the in- and out-degree sequence.
<code>is_multigraphical(sequence)</code>	Returns True if some multigraph can realize the sequence.
<code>is_pseudographical(sequence)</code>	Returns True if some pseudograph can realize the sequence.
<code>is_valid_degree_sequence_havel_hakimi(...)</code>	Returns True if deg_sequence can be realized by a simple graph.
<code>is_valid_degree_sequence_erdos_gallai(...)</code>	Returns True if deg_sequence can be realized by a simple graph.

4.23.1 is_graphical

is_graphical (*sequence*, *method*='eg')

Returns True if sequence is a valid degree sequence.

A degree sequence is valid if some graph can realize it.

Parameters **sequence** (*list or iterable container*) – A sequence of integer node degrees

method ["eg" | "hh"] The method used to validate the degree sequence. "eg" corresponds to the Erdős-Gallai algorithm, and "hh" to the Havel-Hakimi algorithm.

Returns **valid** – True if the sequence is a valid degree sequence and False if not.

Return type bool

Examples

```
>>> G = nx.path_graph(4)
>>> sequence = G.degree().values()
>>> nx.is_valid_degree_sequence(sequence)
True
```

References

Erdős-Gallai [EG1960], [choudum1986]

Havel-Hakimi [havel1955], [hakimi1962], [CL1996]

4.23.2 is_digraphical

is_digraphical (*in_sequence, out_sequence*)

Returns True if some directed graph can realize the in- and out-degree sequences.

Parameters

- **in_sequence** (*list or iterable container*) – A sequence of integer node in-degrees
- **out_sequence** (*list or iterable container*) – A sequence of integer node out-degrees

Returns valid – True if in and out-sequences are digraphic False if not.

Return type `bool`

Notes

This algorithm is from Kleitman and Wang⁵³. The worst case runtime is $O(s * \log n)$ where s and n are the sum and length of the sequences respectively.

References

4.23.3 is_multigraphical

is_multigraphical (*sequence*)

Returns True if some multigraph can realize the sequence.

Parameters deg_sequence (*list*) – A list of integers

Returns valid – True if deg_sequence is a multigraphic degree sequence and False if not.

Return type `bool`

Notes

The worst-case run time is $O(n)$ where n is the length of the sequence.

References

4.23.4 is_pseudographical

is_pseudographical (*sequence*)

Returns True if some pseudograph can realize the sequence.

⁵³ D.J. Kleitman and D.L. Wang Algorithms for Constructing Graphs and Digraphs with Given Valences and Factors, Discrete Mathematics, 6(1), pp. 79-88 (1973)

Every nonnegative integer sequence with an even sum is pseudographical (see ⁵⁴).

Parameters `sequence` (*list or iterable container*) – A sequence of integer node degrees

Returns `valid` – True if the sequence is a pseudographic degree sequence and False if not.

Return type `bool`

Notes

The worst-case run time is $O(n)$ where n is the length of the sequence.

References

4.23.5 `is_valid_degree_sequence_havel_hakimi`

`is_valid_degree_sequence_havel_hakimi` (*deg_sequence*)

Returns True if `deg_sequence` can be realized by a simple graph.

The validation proceeds using the Havel-Hakimi theorem. Worst-case run time is: $O(s)$ where s is the sum of the sequence.

Parameters `deg_sequence` (*list*) – A list of integers where each element specifies the degree of a node in a graph.

Returns `valid` – True if `deg_sequence` is graphical and False if not.

Return type `bool`

Notes

The ZZ condition says that for the sequence d if

$$|d| \geq \frac{(\max(d) + \min(d) + 1)^2}{4 * \min(d)}$$

then d is graphical. This was shown in Theorem 6 in ⁵⁵.

References

[havel1955], [hakimi1962], [CL1996]

4.23.6 `is_valid_degree_sequence_erdos_gallai`

`is_valid_degree_sequence_erdos_gallai` (*deg_sequence*)

Returns True if `deg_sequence` can be realized by a simple graph.

The validation is done using the Erdős-Gallai theorem [EG1960].

Parameters `deg_sequence` (*list*) – A list of integers

Returns `valid` – True if `deg_sequence` is graphical and False if not.

⁵⁴ F. Boesch and F. Harary. "Line removal algorithms for graphs and their degree lists", IEEE Trans. Circuits and Systems, CAS-23(12), pp. 778-782 (1976).

⁵⁵ I.E. Zverovich and V.E. Zverovich. "Contributions to the theory of graphic sequences", Discrete Mathematics, 105, pp. 292-303 (1992).

Return type `bool`

Notes

This implementation uses an equivalent form of the Erdős-Gallai criterion. Worst-case run time is: $O(n)$ where n is the length of the sequence.

Specifically, a sequence d is graphical if and only if the sum of the sequence is even and for all strong indices k in the sequence,

$$\sum_{i=1}^k d_i \leq k(k-1) + \sum_{j=k+1}^n \min(d_i, k) = k(n-1) - (k \sum_{j=0}^{k-1} n_j - \sum_{j=0}^{k-1} j n_j)$$

A strong index k is any index where $d_k \geq k$ and the value n_j is the number of occurrences of j in d . The maximal strong index is called the Durfee index.

This particular rearrangement comes from the proof of Theorem 3 in ⁵⁶.

The ZZ condition says that for the sequence d if

$$|d| \geq \frac{(\max(d) + \min(d) + 1)^2}{4 * \min(d)}$$

then d is graphical. This was shown in Theorem 6 in ².

References

[EG1960], [choudum1986]

4.24 Hierarchy

Flow Hierarchy.

`flow_hierarchy(G[, weight])` Returns the flow hierarchy of a directed network.

4.24.1 flow_hierarchy

flow_hierarchy (G , $weight=None$)

Returns the flow hierarchy of a directed network.

Flow hierarchy is defined as the fraction of edges not participating in cycles in a directed graph ⁵⁷.

Parameters

- **G** (*DiGraph or MultiDiGraph*) – A directed graph

⁵⁶ I.E. Zverovich and V.E. Zverovich. “Contributions to the theory of graphic sequences”, Discrete Mathematics, 105, pp. 292-303 (1992).

⁵⁷ Luo, J.; Magee, C.L. (2011), Detecting evolving patterns of self-organizing networks by flow hierarchy measurement, Complexity, Volume 16 Issue 6 53-61. DOI: 10.1002/cplx.20368 http://web.mit.edu/~cmagee/www/documents/28-DetectingEvolvingPatterns_FlowHierarchy.pdf

- **weight** (*key, optional (default=None)*) – Attribute to use for node weights. If None the weight defaults to 1.

Returns **h** – Flow heirarchy value

Return type `float`

Notes

The algorithm described in ¹ computes the flow hierarchy through exponentiation of the adjacency matrix. This function implements an alternative approach that finds strongly connected components. An edge is in a cycle if and only if it is in a strongly connected component, which can be found in $O(m)$ time using Tarjan's algorithm.

References

4.25 Hybrid

Provides functions for finding and testing for locally (k, l) -connected graphs.

<code>kl_connected_subgraph(G, k, l[, low_memory, ...])</code>	Returns the maximum locally (k, l) -connected subgraph of G .
<code>is_kl_connected(G, k, l[, low_memory])</code>	Returns <code>True</code> if and only if G is locally (k, l) -connected.

4.25.1 kl_connected_subgraph

kl_connected_subgraph ($G, k, l, low_memory=False, same_as_graph=False$)

Returns the maximum locally (k, l) -connected subgraph of G .

A graph is locally (k, l) -connected if for each edge (u, v) in the graph there are at least l edge-disjoint paths of length at most k joining u to v .

Parameters

- **G** (*NetworkX graph*) – The graph in which to find a maximum locally (k, l) -connected subgraph.
- **k** (*integer*) – The maximum length of paths to consider. A higher number means a looser connectivity requirement.
- **l** (*integer*) – The number of edge-disjoint paths. A higher number means a stricter connectivity requirement.
- **low_memory** (*bool*) – If this is `True`, this function uses an algorithm that uses slightly more time but less memory.
- **same_as_graph** (*bool*) – If this is `True` then return a tuple of the form (H, is_same) , where H is the maximum locally (k, l) -connected subgraph and is_same is a Boolean representing whether G is locally (k, l) -connected (and hence, whether H is simply a copy of the input graph G).

Returns If `same_as_graph` is `True`, then this function returns a two-tuple as described above. Otherwise, it returns only the maximum locally (k, l) -connected subgraph.

Return type NetworkX graph or two-tuple

See also:

`is_kl_connected()`

References

4.25.2 is_kl_connected

is_kl_connected(*G*, *k*, *l*, *low_memory=False*)

Returns `True` if and only if *G* is locally (k, l) -connected.

A graph is locally (k, l) -connected if for each edge (u, v) in the graph there are at least *l* edge-disjoint paths of length at most *k* joining *u* to *v*.

Parameters

- **G** (*NetworkX graph*) – The graph to test for local (k, l) -connectedness.
- **k** (*integer*) – The maximum length of paths to consider. A higher number means a looser connectivity requirement.
- **l** (*integer*) – The number of edge-disjoint paths. A higher number means a stricter connectivity requirement.
- **low_memory** (*bool*) – If this is `True`, this function uses an algorithm that uses slightly more time but less memory.

Returns Whether the graph is locally (k, l) -connected subgraph.

Return type `bool`

See also:

`kl_connected_subgraph()`

References

4.26 Isolates

Functions for identifying isolate (degree zero) nodes.

<code>is_isolate(G, n)</code>	Determine if node <i>n</i> is an isolate (degree zero).
<code>isolates(G)</code>	Return list of isolates in the graph.

4.26.1 is_isolate

is_isolate(*G*, *n*)

Determine if node *n* is an isolate (degree zero).

Parameters

- **G** (*graph*) – A networkx graph
- **n** (*node*) – A node in *G*

Returns `isolate` – `True` if *n* has no neighbors, `False` otherwise.

Return type `bool`

Examples

```

>>> G=nx.Graph()
>>> G.add_edge(1,2)
>>> G.add_node(3)
>>> nx.is_isolate(G,2)
False
>>> nx.is_isolate(G,3)
True

```

4.26.2 isolates

isolates(*G*)

Return list of isolates in the graph.

Isolates are nodes with no neighbors (degree zero).

Parameters *G* (*graph*) – A networkx graph

Returns **isolates** – List of isolate nodes.

Return type `list`

Examples

```

>>> G = nx.Graph()
>>> G.add_edge(1,2)
>>> G.add_node(3)
>>> nx.isolates(G)
[3]

```

To remove all isolates in the graph use `>>> G.remove_nodes_from(nx.isolates(G)) >>> G.nodes()` [1, 2]

For digraphs isolates have zero in-degree and zero out_degree `>>> G = nx.DiGraph([(0,1),(1,2)]) >>> G.add_node(3) >>> nx.isolates(G)` [3]

4.27 Isomorphism

4.27.1 Advanced Interface to VF2 Algorithm

VF2 Algorithm

VF2 Algorithm

An implementation of VF2 algorithm for graph isomorphism testing.

The simplest interface to use this module is to call `networkx.is_isomorphic()`.

Introduction The `GraphMatcher` and `DiGraphMatcher` are responsible for matching graphs or directed graphs in a predetermined manner. This usually means a check for an isomorphism, though other checks are also possible. For

example, a subgraph of one graph can be checked for isomorphism to a second graph.

Matching is done via syntactic feasibility. It is also possible to check for semantic feasibility. Feasibility, then, is defined as the logical AND of the two functions.

To include a semantic check, the (Di)GraphMatcher class should be subclassed, and the `semantic_feasibility()` function should be redefined. By default, the semantic feasibility function always returns True. The effect of this is that semantics are not considered in the matching of G1 and G2.

Examples

Suppose G1 and G2 are isomorphic graphs. Verification is as follows:

```
>>> from networkx.algorithms import isomorphism
>>> G1 = nx.path_graph(4)
>>> G2 = nx.path_graph(4)
>>> GM = isomorphism.GraphMatcher(G1,G2)
>>> GM.is_isomorphic()
True
```

GM.mapping stores the isomorphism mapping from G1 to G2.

```
>>> GM.mapping
{0: 0, 1: 1, 2: 2, 3: 3}
```

Suppose G1 and G2 are isomorphic directed graphs. Verification is as follows:

```
>>> G1 = nx.path_graph(4, create_using=nx.DiGraph())
>>> G2 = nx.path_graph(4, create_using=nx.DiGraph())
>>> DiGM = isomorphism.DiGraphMatcher(G1,G2)
>>> DiGM.is_isomorphic()
True
```

DiGM.mapping stores the isomorphism mapping from G1 to G2.

```
>>> DiGM.mapping
{0: 0, 1: 1, 2: 2, 3: 3}
```

Subgraph Isomorphism Graph theory literature can be ambiguous about the meaning of the above statement, and we seek to clarify it now.

In the VF2 literature, a mapping M is said to be a graph-subgraph isomorphism iff M is an isomorphism between G2 and a subgraph of G1. Thus, to say that G1 and G2 are graph-subgraph isomorphic is to say that a subgraph of G1 is isomorphic to G2.

Other literature uses the phrase ‘subgraph isomorphic’ as in ‘G1 does not have a subgraph isomorphic to G2’. Another use is as an in adverb for isomorphic. Thus, to say that G1 and G2 are subgraph isomorphic is to say that a subgraph of G1 is isomorphic to G2.

Finally, the term ‘subgraph’ can have multiple meanings. In this context, ‘subgraph’ always means a ‘node-induced subgraph’. Edge-induced subgraph isomorphisms are not directly supported, but one should be able to perform the check by making use of `nx.line_graph()`. For subgraphs which are not induced, the term ‘monomorphism’ is preferred over ‘isomorphism’. Currently, it is not possible to check for monomorphisms.

Let $G=(N,E)$ be a graph with a set of nodes N and set of edges E.

If $G'=(N',E')$ is a subgraph, then: N' is a subset of N E' is a subset of E

If $G'=(N',E')$ is a node-induced subgraph, then: N' is a subset of N E' is the subset of edges in E relating nodes in N'

If $G'=(N',E')$ is an edge-induced subgraph, then: N' is the subset of nodes in N related by edges in E' E' is a subset of E

References

- [1] Luigi P. Cordella, Pasquale Foggia, Carlo Sansone, Mario Vento, “A (Sub)Graph Isomorphism Algorithm for Matching Large Graphs”, IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 26, no. 10, pp. 1367-1372, Oct., 2004. <http://ieeexplore.ieee.org/iel5/34/29305/01323804.pdf>
- [2] L. P. Cordella, P. Foggia, C. Sansone, M. Vento, “An Improved Algorithm for Matching Large Graphs”, 3rd IAPR-TC15 Workshop on Graph-based Representations in Pattern Recognition, Cuen, pp. 149-159, 2001. <http://amalfi.dis.unina.it/graph/db/papers/vf-algorithm.pdf>

See also:

`syntactic_feasibility`, `semantic_feasibility`

Notes

Modified to handle undirected graphs. Modified to handle multiple edges.

In general, this problem is NP-Complete.

Graph Matcher

DiGraph Matcher

Match helpers

4.28 Link Analysis

4.28.1 PageRank

PageRank analysis of graph structure.

<code>pagerank(G[, alpha, personalization, ...])</code>	Return the PageRank of the nodes in the graph.
<code>pagerank_numpy(G[, alpha, personalization, ...])</code>	Return the PageRank of the nodes in the graph.
<code>pagerank_scipy(G[, alpha, personalization, ...])</code>	Return the PageRank of the nodes in the graph.
<code>google_matrix(G[, alpha, personalization, ...])</code>	Return the Google matrix of the graph.

pagerank

pagerank (*G*, *alpha*=0.85, *personalization*=None, *max_iter*=100, *tol*=1e-06, *nstart*=None, *weight*='weight', *dangling*=None)

Return the PageRank of the nodes in the graph.

PageRank computes a ranking of the nodes in the graph *G* based on the structure of the incoming links. It was originally designed as an algorithm to rank web pages.

Parameters

- **G** (*graph*) – A NetworkX graph. Undirected graphs will be converted to a directed graph with two directed edges for each undirected edge.
- **alpha** (*float, optional*) – Damping parameter for PageRank, default=0.85.
- **personalization** (*dict, optional*) – The “personalization vector” consisting of a dictionary with a key for every graph node and nonzero personalization value for each node. By default, a uniform distribution is used.
- **max_iter** (*integer, optional*) – Maximum number of iterations in power method eigenvalue solver.
- **tol** (*float, optional*) – Error tolerance used to check convergence in power method solver.
- **nstart** (*dictionary, optional*) – Starting value of PageRank iteration for each node.
- **weight** (*key, optional*) – Edge data key to use as weight. If None weights are set to 1.
- **dangling** (*dict, optional*) – The outedges to be assigned to any “dangling” nodes, i.e., nodes without any outedges. The dict key is the node the outedge points to and the dict value is the weight of that outedge. By default, dangling nodes are given outedges according to the personalization vector (uniform if not specified). This must be selected to result in an irreducible transition matrix (see notes under `google_matrix`). It may be common to have the dangling dict to be the same as the personalization dict.

Returns **pagerank** – Dictionary of nodes with PageRank as value

Return type dictionary

Examples

```
>>> G = nx.DiGraph(nx.path_graph(4))
>>> pr = nx.pagerank(G, alpha=0.9)
```

Notes

The eigenvector calculation is done by the power iteration method and has no guarantee of convergence. The iteration will stop after `max_iter` iterations or an error tolerance of `number_of_nodes(G)*tol` has been reached.

The PageRank algorithm was designed for directed graphs but this algorithm does not check if the input graph is directed and will execute on undirected graphs by converting each edge in the directed graph to two edges.

See also:

`pagerank_numpy()`, `pagerank_scipy()`, `google_matrix()`

References

pagerank_numpy

pagerank_numpy (*G*, *alpha*=0.85, *personalization*=None, *weight*='weight', *dangling*=None)

Return the PageRank of the nodes in the graph.

PageRank computes a ranking of the nodes in the graph *G* based on the structure of the incoming links. It was originally designed as an algorithm to rank web pages.

Parameters

- **G** (*graph*) – A NetworkX graph. Undirected graphs will be converted to a directed graph with two directed edges for each undirected edge.
- **alpha** (*float, optional*) – Damping parameter for PageRank, default=0.85.
- **personalization** (*dict, optional*) – The “personalization vector” consisting of a dictionary with a key for every graph node and nonzero personalization value for each node. By default, a uniform distribution is used.
- **weight** (*key, optional*) – Edge data key to use as weight. If None weights are set to 1.
- **dangling** (*dict, optional*) – The outedges to be assigned to any “dangling” nodes, i.e., nodes without any outedges. The dict key is the node the outedge points to and the dict value is the weight of that outedge. By default, dangling nodes are given outedges according to the personalization vector (uniform if not specified) This must be selected to result in an irreducible transition matrix (see notes under `google_matrix`). It may be common to have the dangling dict to be the same as the personalization dict.

Returns pagerank – Dictionary of nodes with PageRank as value.

Return type dictionary

Examples

```
>>> G = nx.DiGraph(nx.path_graph(4))
>>> pr = nx.pagerank_numpy(G, alpha=0.9)
```

Notes

The eigenvector calculation uses NumPy’s interface to the LAPACK eigenvalue solvers. This will be the fastest and most accurate for small graphs.

This implementation works with Multi(Di)Graphs. For multigraphs the weight between two nodes is set to be the sum of all edge weights between those nodes.

See also:

`pagerank()`, `pagerank_scipy()`, `google_matrix()`

References

pagerank_scipy

pagerank_scipy (*G*, *alpha*=0.85, *personalization*=None, *max_iter*=100, *tol*=1e-06, *weight*='weight', *dangling*=None)

Return the PageRank of the nodes in the graph.

PageRank computes a ranking of the nodes in the graph *G* based on the structure of the incoming links. It was originally designed as an algorithm to rank web pages.

Parameters

- **G** (*graph*) – A NetworkX graph. Undirected graphs will be converted to a directed graph with two directed edges for each undirected edge.
- **alpha** (*float, optional*) – Damping parameter for PageRank, default=0.85.
- **personalization** (*dict, optional*) – The “personalization vector” consisting of a dictionary with a key for every graph node and nonzero personalization value for each node. By default, a uniform distribution is used.
- **max_iter** (*integer, optional*) – Maximum number of iterations in power method eigenvalue solver.
- **tol** (*float, optional*) – Error tolerance used to check convergence in power method solver.
- **weight** (*key, optional*) – Edge data key to use as weight. If None weights are set to 1.
- **dangling** (*dict, optional*) – The outedges to be assigned to any “dangling” nodes, i.e., nodes without any outedges. The dict key is the node the outedge points to and the dict value is the weight of that outedge. By default, dangling nodes are given outedges according to the personalization vector (uniform if not specified) This must be selected to result in an irreducible transition matrix (see notes under `google_matrix`). It may be common to have the dangling dict to be the same as the personalization dict.

Returns **pagerank** – Dictionary of nodes with PageRank as value

Return type dictionary

Examples

```
>>> G = nx.DiGraph(nx.path_graph(4))
>>> pr = nx.pagerank_scipy(G, alpha=0.9)
```

Notes

The eigenvector calculation uses power iteration with a SciPy sparse matrix representation.

This implementation works with Multi(Di)Graphs. For multigraphs the weight between two nodes is set to be the sum of all edge weights between those nodes.

See also:

`pagerank()`, `pagerank_numpy()`, `google_matrix()`

References

google_matrix

google_matrix(*G*, *alpha*=0.85, *personalization*=None, *nodelist*=None, *weight*='weight', *dangling*=None)

Return the Google matrix of the graph.

Parameters

- **G** (*graph*) – A NetworkX graph. Undirected graphs will be converted to a directed graph with two directed edges for each undirected edge.
- **alpha** (*float*) – The damping factor.
- **personalization** (*dict*, *optional*) – The “personalization vector” consisting of a dictionary with a key for every graph node and nonzero personalization value for each node. By default, a uniform distribution is used.
- **nodelist** (*list*, *optional*) – The rows and columns are ordered according to the nodes in nodelist. If nodelist is None, then the ordering is produced by `G.nodes()`.
- **weight** (*key*, *optional*) – Edge data key to use as weight. If None weights are set to 1.
- **dangling** (*dict*, *optional*) – The outedges to be assigned to any “dangling” nodes, i.e., nodes without any outedges. The dict key is the node the outedge points to and the dict value is the weight of that outedge. By default, dangling nodes are given outedges according to the personalization vector (uniform if not specified) This must be selected to result in an irreducible transition matrix (see notes below). It may be common to have the dangling dict to be the same as the personalization dict.

Returns **A** – Google matrix of the graph

Return type NumPy matrix

Notes

The matrix returned represents the transition matrix that describes the Markov chain used in PageRank. For PageRank to converge to a unique solution (i.e., a unique stationary distribution in a Markov chain), the transition matrix must be irreducible. In other words, it must be that there exists a path between every pair of nodes in the graph, or else there is the potential of “rank sinks.”

This implementation works with Multi(Di)Graphs. For multigraphs the weight between two nodes is set to be the sum of all edge weights between those nodes.

See also:

`pagerank()`, `pagerank_numpy()`, `pagerank_scipy()`

4.28.2 Hits

Hubs and authorities analysis of graph structure.

<code>hits(G[, max_iter, tol, nstart, normalized])</code>	Return HITS hubs and authorities values for nodes.
<code>hits_numpy(G[, normalized])</code>	Return HITS hubs and authorities values for nodes.
<code>hits_scipy(G[, max_iter, tol, normalized])</code>	Return HITS hubs and authorities values for nodes.
<code>hub_matrix(G[, nodelist])</code>	Return the HITS hub matrix.

Continued on next page

Table 4.76 – continued from previous page

<code>authority_matrix(G[, nodelist])</code>	Return the HITS authority matrix.
--	-----------------------------------

hits

hits (*G*, *max_iter*=100, *tol*=1e-08, *nstart*=None, *normalized*=True)

Return HITS hubs and authorities values for nodes.

The HITS algorithm computes two numbers for a node. Authorities estimates the node value based on the incoming links. Hubs estimates the node value based on outgoing links.

Parameters

- **G** (*graph*) – A NetworkX graph
- **max_iter** (*integer, optional*) – Maximum number of iterations in power method.
- **tol** (*float, optional*) – Error tolerance used to check convergence in power method iteration.
- **nstart** (*dictionary, optional*) – Starting value of each node for power method iteration.
- **normalized** (*bool (default=True)*) – Normalize results by the sum of all of the values.

Returns (hubs,authorities) – Two dictionaries keyed by node containing the hub and authority values.

Return type two-tuple of dictionaries

Examples

```
>>> G=nx.path_graph(4)
>>> h,a=nx.hits(G)
```

Notes

The eigenvector calculation is done by the power iteration method and has no guarantee of convergence. The iteration will stop after *max_iter* iterations or an error tolerance of *number_of_nodes(G)*tol* has been reached.

The HITS algorithm was designed for directed graphs but this algorithm does not check if the input graph is directed and will execute on undirected graphs.

References

hits_numpy

hits_numpy (*G*, *normalized*=True)

Return HITS hubs and authorities values for nodes.

The HITS algorithm computes two numbers for a node. Authorities estimates the node value based on the incoming links. Hubs estimates the node value based on outgoing links.

G [*graph*] A NetworkX graph

normalized [*bool (default=True)*] Normalize results by the sum of all of the values.

Returns (hubs,authorities) – Two dictionaries keyed by node containing the hub and authority values.

Return type two-tuple of dictionaries

Examples

```
>>> G=nx.path_graph(4)
>>> h,a=nx.hits(G)
```

Notes

The eigenvector calculation uses NumPy's interface to LAPACK.

The HITS algorithm was designed for directed graphs but this algorithm does not check if the input graph is directed and will execute on undirected graphs.

References

hits_scipy

hits_scipy (*G*, *max_iter*=100, *tol*=1e-06, *normalized*=True)

Return HITS hubs and authorities values for nodes.

The HITS algorithm computes two numbers for a node. Authorities estimates the node value based on the incoming links. Hubs estimates the node value based on outgoing links.

G [graph] A NetworkX graph

max_iter [integer, optional] Maximum number of iterations in power method.

tol [float, optional] Error tolerance used to check convergence in power method iteration.

nstart [dictionary, optional] Starting value of each node for power method iteration.

normalized [bool (default=True)] Normalize results by the sum of all of the values.

Returns (hubs,authorities) – Two dictionaries keyed by node containing the hub and authority values.

Return type two-tuple of dictionaries

Examples

```
>>> G=nx.path_graph(4)
>>> h,a=nx.hits(G)
```

Notes

This implementation uses SciPy sparse matrices.

The eigenvector calculation is done by the power iteration method and has no guarantee of convergence. The iteration will stop after *max_iter* iterations or an error tolerance of *number_of_nodes(G)*tol* has been reached.

The HITS algorithm was designed for directed graphs but this algorithm does not check if the input graph is directed and will execute on undirected graphs.

References

hub_matrix

hub_matrix (*G*, *nodelist=None*)
Return the HITS hub matrix.

authority_matrix

authority_matrix (*G*, *nodelist=None*)
Return the HITS authority matrix.

4.29 Link Prediction

Link prediction algorithms.

<code>resource_allocation_index</code> (<i>G</i> [, <i>ebunch</i>])	Compute the resource allocation index of all node pairs in <i>ebunch</i> .
<code>jaccard_coefficient</code> (<i>G</i> [, <i>ebunch</i>])	Compute the Jaccard coefficient of all node pairs in <i>ebunch</i> .
<code>adamic_adar_index</code> (<i>G</i> [, <i>ebunch</i>])	Compute the Adamic-Adar index of all node pairs in <i>ebunch</i> .
<code>preferential_attachment</code> (<i>G</i> [, <i>ebunch</i>])	Compute the preferential attachment score of all node pairs in <i>ebunch</i> .
<code>cn_soundarajan_hopcroft</code> (<i>G</i> [, <i>ebunch</i> , <i>community</i>])	Count the number of common neighbors of all node pairs in <i>ebunch</i> using <i>community</i> .
<code>ra_index_soundarajan_hopcroft</code> (<i>G</i> [, <i>ebunch</i> , ...])	Compute the resource allocation index of all node pairs in <i>ebunch</i> using <i>ra_index_soundarajan_hopcroft</i> .
<code>within_inter_cluster</code> (<i>G</i> [, <i>ebunch</i> , <i>delta</i> , ...])	Compute the ratio of within- and inter-cluster common neighbors of all node pairs in <i>ebunch</i> .

4.29.1 resource_allocation_index

resource_allocation_index (*G*, *ebunch=None*)
Compute the resource allocation index of all node pairs in *ebunch*.

Resource allocation index of *u* and *v* is defined as

$$\sum_{w \in \Gamma(u) \cap \Gamma(v)} \frac{1}{|\Gamma(w)|}$$

where $\Gamma(u)$ denotes the set of neighbors of *u*.

Parameters

- **G** (*graph*) – A NetworkX undirected graph.
- **ebunch** (*iterable of node pairs, optional (default = None)*) – Resource allocation index will be computed for each pair of nodes given in the iterable. The pairs must be given as 2-tuples (*u*, *v*) where *u* and *v* are nodes in the graph. If *ebunch* is *None* then all non-existent edges in the graph will be used. Default value: *None*.

Returns **piter** – An iterator of 3-tuples in the form (*u*, *v*, *p*) where (*u*, *v*) is a pair of nodes and *p* is their resource allocation index.

Return type iterator

Examples

```
>>> import networkx as nx
>>> G = nx.complete_graph(5)
>>> preds = nx.resource_allocation_index(G, [(0, 1), (2, 3)])
>>> for u, v, p in preds:
...     '(%d, %d) -> %.8f' % (u, v, p)
...
'(0, 1) -> 0.75000000'
'(2, 3) -> 0.75000000'
```

References

4.29.2 jaccard_coefficient

jaccard_coefficient (*G*, *ebunch*=None)

Compute the Jaccard coefficient of all node pairs in ebunch.

Jaccard coefficient of nodes *u* and *v* is defined as

$$\frac{|\Gamma(u) \cap \Gamma(v)|}{|\Gamma(u) \cup \Gamma(v)|}$$

where $\Gamma(u)$ denotes the set of neighbors of *u*.

Parameters

- **G** (*graph*) – A NetworkX undirected graph.
- **ebunch** (*iterable of node pairs, optional (default = None)*) – Jaccard coefficient will be computed for each pair of nodes given in the iterable. The pairs must be given as 2-tuples (*u*, *v*) where *u* and *v* are nodes in the graph. If *ebunch* is None then all non-existent edges in the graph will be used. Default value: None.

Returns **piter** – An iterator of 3-tuples in the form (*u*, *v*, *p*) where (*u*, *v*) is a pair of nodes and *p* is their Jaccard coefficient.

Return type iterator

Examples

```
>>> import networkx as nx
>>> G = nx.complete_graph(5)
>>> preds = nx.jaccard_coefficient(G, [(0, 1), (2, 3)])
>>> for u, v, p in preds:
...     '(%d, %d) -> %.8f' % (u, v, p)
...
'(0, 1) -> 0.60000000'
'(2, 3) -> 0.60000000'
```

References

4.29.3 adamic_adar_index

adamic_adar_index (*G*, *ebunch*=None)

Compute the Adamic-Adar index of all node pairs in ebunch.

Adamic-Adar index of u and v is defined as

$$\sum_{w \in \Gamma(u) \cap \Gamma(v)} \frac{1}{\log |\Gamma(w)|}$$

where $\Gamma(u)$ denotes the set of neighbors of u .

Parameters

- **G** (*graph*) – NetworkX undirected graph.
- **ebunch** (*iterable of node pairs, optional (default = None)*) – Adamic-Adar index will be computed for each pair of nodes given in the iterable. The pairs must be given as 2-tuples (u, v) where u and v are nodes in the graph. If **ebunch** is *None* then all non-existent edges in the graph will be used. Default value: *None*.

Returns **piter** – An iterator of 3-tuples in the form (u, v, p) where (u, v) is a pair of nodes and p is their Adamic-Adar index.

Return type iterator

Examples

```
>>> import networkx as nx
>>> G = nx.complete_graph(5)
>>> preds = nx.adamic_adar_index(G, [(0, 1), (2, 3)])
>>> for u, v, p in preds:
...     '(%d, %d) -> %.8f' % (u, v, p)
...
' (0, 1) -> 2.16404256 '
' (2, 3) -> 2.16404256 '
```

References

4.29.4 preferential_attachment

preferential_attachment (*G, ebunch=None*)

Compute the preferential attachment score of all node pairs in **ebunch**.

Preferential attachment score of u and v is defined as

$$|\Gamma(u)||\Gamma(v)|$$

where $\Gamma(u)$ denotes the set of neighbors of u .

Parameters

- **G** (*graph*) – NetworkX undirected graph.
- **ebunch** (*iterable of node pairs, optional (default = None)*) – Preferential attachment score will be computed for each pair of nodes given in the iterable. The pairs must be given as 2-tuples (u, v) where u and v are nodes in the graph. If **ebunch** is *None* then all non-existent edges in the graph will be used. Default value: *None*.

Returns **piter** – An iterator of 3-tuples in the form (u, v, p) where (u, v) is a pair of nodes and p is their preferential attachment score.

Return type iterator

Examples

```
>>> import networkx as nx
>>> G = nx.complete_graph(5)
>>> preds = nx.preferential_attachment(G, [(0, 1), (2, 3)])
>>> for u, v, p in preds:
...     '(%d, %d) -> %d' % (u, v, p)
...
' (0, 1) -> 16 '
' (2, 3) -> 16 '
```

References

4.29.5 cn_soundarajan_hopcroft

cn_soundarajan_hopcroft (*G*, *ebunch*=None, *community*='community')

Count the number of common neighbors of all node pairs in ebunch using community information.

For two nodes u and v , this function computes the number of common neighbors and bonus one for each common neighbor belonging to the same community as u and v . Mathematically,

$$|\Gamma(u) \cap \Gamma(v)| + \sum_{w \in \Gamma(u) \cap \Gamma(v)} f(w)$$

where $f(w)$ equals 1 if w belongs to the same community as u and v or 0 otherwise and $\Gamma(u)$ denotes the set of neighbors of u .

Parameters

- **G** (*graph*) – A NetworkX undirected graph.
- **ebunch** (*iterable of node pairs, optional (default = None)*) – The score will be computed for each pair of nodes given in the iterable. The pairs must be given as 2-tuples (u, v) where u and v are nodes in the graph. If ebunch is None then all non-existent edges in the graph will be used. Default value: None.
- **community** (*string, optional (default = 'community')*) – Nodes attribute name containing the community information. $G[u][community]$ identifies which community u belongs to. Each node belongs to at most one community. Default value: 'community'.

Returns piter – An iterator of 3-tuples in the form (u, v, p) where (u, v) is a pair of nodes and p is their score.

Return type iterator

Examples

```
>>> import networkx as nx
>>> G = nx.path_graph(3)
>>> G.node[0]['community'] = 0
>>> G.node[1]['community'] = 0
>>> G.node[2]['community'] = 0
>>> preds = nx.cn_soundarajan_hopcroft(G, [(0, 2)])
>>> for u, v, p in preds:
...     '(%d, %d) -> %d' % (u, v, p)
```

```
...
'(0, 2) -> 2'
```

References

4.29.6 ra_index_soundarajan_hopcroft

ra_index_soundarajan_hopcroft (*G*, *ebunch*=None, *community*='community')

Compute the resource allocation index of all node pairs in *ebunch* using community information.

For two nodes *u* and *v*, this function computes the resource allocation index considering only common neighbors belonging to the same community as *u* and *v*. Mathematically,

$$\sum_{w \in \Gamma(u) \cap \Gamma(v)} \frac{f(w)}{|\Gamma(w)|}$$

where $f(w)$ equals 1 if *w* belongs to the same community as *u* and *v* or 0 otherwise and $\Gamma(u)$ denotes the set of neighbors of *u*.

Parameters

- **G** (*graph*) – A NetworkX undirected graph.
- **ebunch** (*iterable of node pairs, optional (default = None)*) – The score will be computed for each pair of nodes given in the iterable. The pairs must be given as 2-tuples (*u*, *v*) where *u* and *v* are nodes in the graph. If *ebunch* is None then all non-existent edges in the graph will be used. Default value: None.
- **community** (*string, optional (default = 'community')*) – Nodes attribute name containing the community information. *G[u][community]* identifies which community *u* belongs to. Each node belongs to at most one community. Default value: 'community'.

Returns **piter** – An iterator of 3-tuples in the form (*u*, *v*, *p*) where (*u*, *v*) is a pair of nodes and *p* is their score.

Return type iterator

Examples

```
>>> import networkx as nx
>>> G = nx.Graph()
>>> G.add_edges_from([(0, 1), (0, 2), (1, 3), (2, 3)])
>>> G.node[0]['community'] = 0
>>> G.node[1]['community'] = 0
>>> G.node[2]['community'] = 1
>>> G.node[3]['community'] = 0
>>> preds = nx.ra_index_soundarajan_hopcroft(G, [(0, 3)])
>>> for u, v, p in preds:
...     '(%d, %d) -> %.8f' % (u, v, p)
...
'(0, 3) -> 0.50000000'
```


References

4.29.7 within_inter_cluster

within_inter_cluster (*G*, *ebunch*=None, *delta*=0.001, *community*='community')

Compute the ratio of within- and inter-cluster common neighbors of all node pairs in *ebunch*.

For two nodes *u* and *v*, if a common neighbor *w* belongs to the same community as them, *w* is considered as within-cluster common neighbor of *u* and *v*. Otherwise, it is considered as inter-cluster common neighbor of *u* and *v*. The ratio between the size of the set of within- and inter-cluster common neighbors is defined as the WIC measure.⁵⁸

Parameters

- **G** (*graph*) – A NetworkX undirected graph.
- **ebunch** (*iterable of node pairs, optional (default = None)*) – The WIC measure will be computed for each pair of nodes given in the iterable. The pairs must be given as 2-tuples (*u*, *v*) where *u* and *v* are nodes in the graph. If *ebunch* is None then all non-existent edges in the graph will be used. Default value: None.
- **delta** (*float, optional (default = 0.001)*) – Value to prevent division by zero in case there is no inter-cluster common neighbor between two nodes. See ¹ for details. Default value: 0.001.
- **community** (*string, optional (default = 'community')*) – Nodes attribute name containing the community information. *G[u][community]* identifies which community *u* belongs to. Each node belongs to at most one community. Default value: 'community'.

Returns **piter** – An iterator of 3-tuples in the form (*u*, *v*, *p*) where (*u*, *v*) is a pair of nodes and *p* is their WIC measure.

Return type iterator

Examples

```
>>> import networkx as nx
>>> G = nx.Graph()
>>> G.add_edges_from([(0, 1), (0, 2), (0, 3), (1, 4), (2, 4), (3, 4)])
>>> G.node[0]['community'] = 0
>>> G.node[1]['community'] = 1
>>> G.node[2]['community'] = 0
>>> G.node[3]['community'] = 0
>>> G.node[4]['community'] = 0
>>> preds = nx.within_inter_cluster(G, [(0, 4)])
>>> for u, v, p in preds:
...     '(%d, %d) -> %.8f' % (u, v, p)
...
'(0, 4) -> 1.99800200'
>>> preds = nx.within_inter_cluster(G, [(0, 4)], delta=0.5)
>>> for u, v, p in preds:
...     '(%d, %d) -> %.8f' % (u, v, p)
...
'(0, 4) -> 1.33333333'
```

⁵⁸ Jorge Carlos Valverde-Rebaza and Alneu de Andrade Lopes. Link prediction in complex networks based on cluster information. In Proceedings of the 21st Brazilian conference on Advances in Artificial Intelligence (SBIA'12) http://dx.doi.org/10.1007/978-3-642-34459-6_10

References

4.30 Matching

4.30.1 Matching

<code>maximal_matching(G)</code>	Find a maximal cardinality matching in the graph.
<code>max_weight_matching(G[, maxcardinality])</code>	Compute a maximum-weighted matching of G.

4.30.2 maximal_matching

maximal_matching(*G*)

Find a maximal cardinality matching in the graph.

A matching is a subset of edges in which no node occurs more than once. The cardinality of a matching is the number of matched edges.

Parameters *G* (*NetworkX graph*) – Undirected graph

Returns **matching** – A maximal matching of the graph.

Return type `set`

Notes

The algorithm greedily selects a maximal matching *M* of the graph *G* (i.e. no superset of *M* exists). It runs in $O(|E|)$ time.

4.30.3 max_weight_matching

max_weight_matching(*G*, *maxcardinality=False*)

Compute a maximum-weighted matching of *G*.

A matching is a subset of edges in which no node occurs more than once. The cardinality of a matching is the number of matched edges. The weight of a matching is the sum of the weights of its edges.

Parameters

- *G* (*NetworkX graph*) – Undirected graph
- **maxcardinality** (*bool, optional*) – If *maxcardinality* is `True`, compute the maximum-cardinality matching with maximum weight among all maximum-cardinality matchings.

Returns **mate** – The matching is returned as a dictionary, *mate*, such that *mate*[*v*] == *w* if node *v* is matched to node *w*. Unmatched nodes do not occur as a key in *mate*.

Return type `dictionary`

If *G* has edges with ‘weight’ attribute the edge data are used as weight values else the weights are assumed to be 1.

This function takes time $O(\text{number_of_nodes}^3)$.

If all edge weights are integers, the algorithm uses only integer computations. If floating point weights are used, the algorithm could return a slightly suboptimal matching due to numeric precision errors.

This method is based on the “blossom” method for finding augmenting paths and the “primal-dual” method for finding a matching of maximum weight, both methods invented by Jack Edmonds⁵⁹.

Bipartite graphs can also be matched using the functions present in `networkx.algorithms.bipartite.matching`.

References

4.31 Minors

Provides functions for computing minors of a graph.

<code>contracted_edge(G, edge[, self_loops])</code>	Returns the graph that results from contracting the specified edge.
<code>contracted_nodes(G, u, v[, self_loops])</code>	Returns the graph that results from contracting <code>u</code> and <code>v</code> .
<code>identified_nodes(G, u, v[, self_loops])</code>	Returns the graph that results from contracting <code>u</code> and <code>v</code> .
<code>quotient_graph(G, node_relation[, ...])</code>	Returns the quotient graph of <code>G</code> under the specified equivalence relation on nodes.

4.31.1 contracted_edge

contracted_edge (*G*, *edge*, *self_loops=True*)

Returns the graph that results from contracting the specified edge.

Edge contraction identifies the two endpoints of the edge as a single node incident to any edge that was incident to the original two nodes. A graph that results from edge contraction is called a *minor* of the original graph.

Parameters

- **G** (*NetworkX graph*) – The graph whose edge will be contracted.
- **edge** (*tuple*) – Must be a pair of nodes in `G`.
- **self_loops** (*Boolean*) – If this is `True`, any edges (including `edge`) joining the endpoints of `edge` in `G` become self-loops on the new node in the returned graph.

Returns A new graph object of the same type as `G` (leaving `G` unmodified) with endpoints of `edge` identified in a single node. The right node of `edge` will be merged into the left one, so only the left one will appear in the returned graph.

Return type Networkx graph

Raises `ValueError` – If `edge` is not an edge in `G`.

Examples

Attempting to contract two nonadjacent nodes yields an error:

```
>>> import networkx as nx
>>> G = nx.cycle_graph(4)
>>> nx.contracted_edge(G, (1, 3))
Traceback (most recent call last):
...
ValueError: Edge (1, 3) does not exist in graph G; cannot contract it
Traceback (most recent call last):
```

⁵⁹ “Efficient Algorithms for Finding Maximum Matching in Graphs”, Zvi Galil, ACM Computing Surveys, 1986.

```
...
ValueError: Edge (1, 3) does not exist in graph G; cannot contract it
```

Contracting two adjacent nodes in the cycle graph on n nodes yields the cycle graph on $n - 1$ nodes:

```
>>> import networkx as nx
>>> C5 = nx.cycle_graph(5)
>>> C4 = nx.cycle_graph(4)
>>> M = nx.contracted_edge(C5, (0, 1), self_loops=False)
>>> nx.is_isomorphic(M, C4)
True
```

See also:

`contracted_nodes()`, `quotient_graph()`

4.31.2 contracted_nodes

contracted_nodes ($G, u, v, self_loops=True$)

Returns the graph that results from contracting u and v .

Node contraction identifies the two nodes as a single node incident to any edge that was incident to the original two nodes.

Parameters

- **G** (*NetworkX graph*) – The graph whose nodes will be contracted.
- **$v(u,)$** – Must be nodes in G .
- **`self_loops`** (*Boolean*) – If this is `True`, any edges joining u and v in G become self-loops on the new node in the returned graph.

Returns A new graph object of the same type as G (leaving G unmodified) with u and v identified in a single node. The right node v will be merged into the node u , so only u will appear in the returned graph.

Return type Networkx graph

Examples

Contracting two nonadjacent nodes of the cycle graph on four nodes C_4 yields the path graph (ignoring parallel edges):

```
>>> import networkx as nx
>>> G = nx.cycle_graph(4)
>>> M = nx.contracted_nodes(G, 1, 3)
>>> P3 = nx.path_graph(3)
>>> nx.is_isomorphic(M, P3)
True
```

See also:

`contracted_edge()`, `quotient_graph()`

Notes

This function is also available as `identified_nodes`.

4.31.3 identified_nodes

identified_nodes (*G*, *u*, *v*, *self_loops=True*)

Returns the graph that results from contracting *u* and *v*.

Node contraction identifies the two nodes as a single node incident to any edge that was incident to the original two nodes.

Parameters

- **G** (*NetworkX graph*) – The graph whose nodes will be contracted.
- **v** (*u*,) – Must be nodes in *G*.
- **self_loops** (*Boolean*) – If this is `True`, any edges joining *u* and *v* in *G* become self-loops on the new node in the returned graph.

Returns A new graph object of the same type as *G* (leaving *G* unmodified) with *u* and *v* identified in a single node. The right node *v* will be merged into the node *u*, so only *u* will appear in the returned graph.

Return type Networkx graph

Examples

Contracting two nonadjacent nodes of the cycle graph on four nodes C_4 yields the path graph (ignoring parallel edges):

```
>>> import networkx as nx
>>> G = nx.cycle_graph(4)
>>> M = nx.contracted_nodes(G, 1, 3)
>>> P3 = nx.path_graph(3)
>>> nx.is_isomorphic(M, P3)
True
```

See also:

`contracted_edge()`, `quotient_graph()`

Notes

This function is also available as `identified_nodes`.

4.31.4 quotient_graph

quotient_graph (*G*, *node_relation*, *edge_relation=None*, *create_using=None*)

Returns the quotient graph of *G* under the specified equivalence relation on nodes.

Parameters

- **G** (*NetworkX graph*) – The graph for which to return the quotient graph with the specified node relation.
- **node_relation** (*Boolean function with two arguments*) – This function must represent an equivalence relation on the nodes of *G*. It must take two arguments *u* and *v* and return `True` exactly when *u* and *v* are in the same equivalence class. The equivalence classes form the nodes in the returned graph.

- **edge_relation** (*Boolean function with two arguments*) – This function must represent an edge relation on the *blocks* of G in the partition induced by *node_relation*. It must take two arguments, B and C , each one a set of nodes, and return `True` exactly when there should be an edge joining block B to block C in the returned graph.

If *edge_relation* is not specified, it is assumed to be the following relation. Block B is related to block C if and only if some node in B is adjacent to some node in C , according to the edge set of G .

- **create_using** (*NetworkX graph*) – If specified, this must be an instance of a NetworkX graph class. The nodes and edges of the quotient graph will be added to this graph and returned. If not specified, the returned graph will have the same type as the input graph.

Returns The quotient graph of G under the equivalence relation specified by *node_relation*.

Return type NetworkX graph

Examples

The quotient graph of the complete bipartite graph under the “same neighbors” equivalence relation is K_2 . Under this relation, two nodes are equivalent if they are not adjacent but have the same neighbor set:

```
>>> import networkx as nx
>>> G = nx.complete_bipartite_graph(2, 3)
>>> same_neighbors = lambda u, v: (u not in G[v] and v not in G[u]
...                               and G[u] == G[v])
>>> Q = nx.quotient_graph(G, same_neighbors)
>>> K2 = nx.complete_graph(2)
>>> nx.is_isomorphic(Q, K2)
True
```

The quotient graph of a directed graph under the “same strongly connected component” equivalence relation is the condensation of the graph (see `condensation()`). This example comes from the Wikipedia article ‘*Strongly connected component*’:

```
>>> import networkx as nx
>>> G = nx.DiGraph()
>>> edges = ['ab', 'be', 'bf', 'bc', 'cg', 'cd', 'dc', 'dh', 'ea',
...         'ef', 'fg', 'gf', 'hd', 'hf']
>>> G.add_edges_from(tuple(x) for x in edges)
>>> components = list(nx.strongly_connected_components(G))
>>> sorted(sorted(component) for component in components)
[['a', 'b', 'e'], ['c', 'd', 'h'], ['f', 'g']]
>>>
>>> C = nx.condensation(G, components)
>>> component_of = C.graph['mapping']
>>> same_component = lambda u, v: component_of[u] == component_of[v]
>>> Q = nx.quotient_graph(G, same_component)
>>> nx.is_isomorphic(C, Q)
True
```

Node identification can be represented as the quotient of a graph under the equivalence relation that places the two nodes in one block and each other node in its own singleton block:

```
>>> import networkx as nx
>>> K24 = nx.complete_bipartite_graph(2, 4)
>>> K34 = nx.complete_bipartite_graph(3, 4)
>>> C = nx.contracted_nodes(K34, 1, 2)
>>> nodes = {1, 2}
```

```

>>> is_contracted = lambda u, v: u in nodes and v in nodes
>>> Q = nx.quotient_graph(K34, is_contracted)
>>> nx.is_isomorphic(Q, C)
True
>>> nx.is_isomorphic(Q, K24)
True

```

4.32 Maximal independent set

Algorithm to find a maximal (not maximum) independent set.

`maximal_independent_set(G[, nodes])` Return a random maximal independent set guaranteed to contain a given set of nodes.

4.32.1 maximal_independent_set

maximal_independent_set (*G*, *nodes=None*)

Return a random maximal independent set guaranteed to contain a given set of nodes.

An independent set is a set of nodes such that the subgraph of *G* induced by these nodes contains no edges. A maximal independent set is an independent set such that it is not possible to add a new node and still get an independent set.

Parameters

- **G** (*NetworkX graph*) –
- **nodes** (*list or iterable*) – Nodes that must be part of the independent set. This set of nodes must be independent.

Returns **indep_nodes** – List of nodes that are part of a maximal independent set.

Return type **list**

Raises **NetworkXUnfeasible** – If the nodes in the provided list are not part of the graph or do not form an independent set, an exception is raised.

Examples

```

>>> G = nx.path_graph(5)
>>> nx.maximal_independent_set(G)
[4, 0, 2]
>>> nx.maximal_independent_set(G, [1])
[1, 3]

```

This algorithm does not solve the maximum independent set problem.

4.33 Minimum Spanning Tree

Computes minimum spanning tree of a weighted graph.

`minimum_spanning_tree(G[, weight])` Return a minimum spanning tree or forest of an undirected weighted graph.
`minimum_spanning_edges(G[, weight, data])` Generate edges in a minimum spanning forest of an undirected weighted graph.

4.33.1 minimum_spanning_tree

minimum_spanning_tree (*G*, *weight*='weight')

Return a minimum spanning tree or forest of an undirected weighted graph.

A minimum spanning tree is a subgraph of the graph (a tree) with the minimum sum of edge weights.

If the graph is not connected a spanning forest is constructed. A spanning forest is a union of the spanning trees for each connected component of the graph.

Parameters

- **G** (*NetworkX Graph*) –
- **weight** (*string*) – Edge data key to use for weight (default 'weight').

Returns **G** – A minimum spanning tree or forest.

Return type NetworkX Graph

Examples

```
>>> G=nx.cycle_graph(4)
>>> G.add_edge(0,3,weight=2) # assign weight 2 to edge 0-3
>>> T=nx.minimum_spanning_tree(G)
>>> print(sorted(T.edges(data=True)))
[(0, 1, {}), (1, 2, {}), (2, 3, {})]
```

Notes

Uses Kruskal's algorithm.

If the graph edges do not have a weight attribute a default weight of 1 will be used.

4.33.2 minimum_spanning_edges

minimum_spanning_edges (*G*, *weight*='weight', *data*=True)

Generate edges in a minimum spanning forest of an undirected weighted graph.

A minimum spanning tree is a subgraph of the graph (a tree) with the minimum sum of edge weights. A spanning forest is a union of the spanning trees for each connected component of the graph.

Parameters

- **G** (*NetworkX Graph*) –
- **weight** (*string*) – Edge data key to use for weight (default 'weight').
- **data** (*bool, optional*) – If True yield the edge data along with the edge.

Returns **edges** – A generator that produces edges in the minimum spanning tree. The edges are three-tuples (u,v,w) where w is the weight.

Return type iterator

Examples

```
>>> G=nx.cycle_graph(4)
>>> G.add_edge(0,3,weight=2) # assign weight 2 to edge 0-3
>>> mst=nx.minimum_spanning_edges(G,data=False) # a generator of MST edges
>>> edgelist=list(mst) # make a list of the edges
>>> print(sorted(edgelist))
[(0, 1), (1, 2), (2, 3)]
```

Notes

Uses Kruskal's algorithm.

If the graph edges do not have a weight attribute a default weight of 1 will be used.

Modified code from David Eppstein, April 2006 <http://www.ics.uci.edu/~eppstein/PADS/>

4.34 Operators

Unary operations on graphs

<code>complement(G[, name])</code>	Return the graph complement of G.
<code>reverse(G[, copy])</code>	Return the reverse directed graph of G.

4.34.1 complement

complement (*G*, *name=None*)

Return the graph complement of G.

Parameters

- **G** (*graph*) – A NetworkX graph
- **name** (*string*) – Specify name for new graph

Returns

- **GC** (*A new graph.*)
- *Notes*
- —
- *Note that complement() does not create self-loops and also*
- *does not produce parallel edges for MultiGraphs.*
- *Graph, node, and edge data are not propagated to the new graph.*

4.34.2 reverse

reverse (*G*, *copy=True*)

Return the reverse directed graph of G.

Parameters

- **G** (*directed graph*) – A NetworkX directed graph
- **copy** (*bool*) – If True, then a new graph is returned. If False, then the graph is reversed in place.

Returns **H** – The reversed G.

Return type directed graph

Operations on graphs including union, intersection, difference.

<code>compose(G, H[, name])</code>	Return a new graph of G composed with H.
<code>union(G, H[, rename, name])</code>	Return the union of graphs G and H.
<code>disjoint_union(G, H)</code>	Return the disjoint union of graphs G and H.
<code>intersection(G, H)</code>	Return a new graph that contains only the edges that exist in both G and H.
<code>difference(G, H)</code>	Return a new graph that contains the edges that exist in G but not in H.
<code>symmetric_difference(G, H)</code>	Return new graph with edges that exist in either G or H but not both.

4.34.3 compose

compose (*G, H, name=None*)

Return a new graph of G composed with H.

Composition is the simple union of the node sets and edge sets. The node sets of G and H do not need to be disjoint.

Parameters

- **G, H** (*graph*) – A NetworkX graph
- **name** (*string*) – Specify name for new graph

Returns **C**

Return type A new graph with the same type as G

Notes

It is recommended that G and H be either both directed or both undirected. Attributes from H take precedent over attributes from G.

4.34.4 union

union (*G, H, rename=(None, None), name=None*)

Return the union of graphs G and H.

Graphs G and H must be disjoint, otherwise an exception is raised.

Parameters

- **G, H** (*graph*) – A NetworkX graph
- **create_using** (*NetworkX graph*) – Use specified graph for result. Otherwise
- **rename** (*bool* , *default=(None, None)*) – Node names of G and H can be changed by specifying the tuple `rename=('G-', 'H-')` (for example). Node “u” in G is then renamed “G-u” and “v” in H is renamed “H-v”.
- **name** (*string*) – Specify the name for the union graph

Returns *U*

Return type A union graph with the same type as *G*.

Notes

To force a disjoint union with node relabeling, use `disjoint_union(G,H)` or `convert_node_labels_to_integers()`.

Graph, edge, and node attributes are propagated from *G* and *H* to the union graph. If a graph attribute is present in both *G* and *H* the value from *H* is used.

See also:

`disjoint_union()`

4.34.5 disjoint_union

disjoint_union (*G*, *H*)

Return the disjoint union of graphs *G* and *H*.

This algorithm forces distinct integer node labels.

Parameters *G*, *H* (*graph*) – A NetworkX graph

Returns *U*

Return type A union graph with the same type as *G*.

Notes

A new graph is created, of the same class as *G*. It is recommended that *G* and *H* be either both directed or both undirected.

The nodes of *G* are relabeled 0 to `len(G)-1`, and the nodes of *H* are relabeled `len(G)` to `len(G)+len(H)-1`.

Graph, edge, and node attributes are propagated from *G* and *H* to the union graph. If a graph attribute is present in both *G* and *H* the value from *H* is used.

4.34.6 intersection

intersection (*G*, *H*)

Return a new graph that contains only the edges that exist in both *G* and *H*.

The node sets of *H* and *G* must be the same.

Parameters *G*, *H* (*graph*) – A NetworkX graph. *G* and *H* must have the same node sets.

Returns *GH*

Return type A new graph with the same type as *G*.

Notes

Attributes from the graph, nodes, and edges are not copied to the new graph. If you want a new graph of the intersection of *G* and *H* with the attributes (including edge data) from *G* use `remove_nodes_from()` as follows

```
>>> G=nx.path_graph(3)
>>> H=nx.path_graph(5)
>>> R=G.copy()
>>> R.remove_nodes_from(n for n in G if n not in H)
```

4.34.7 difference

difference (*G*, *H*)

Return a new graph that contains the edges that exist in *G* but not in *H*.

The node sets of *H* and *G* must be the same.

Parameters *G*, *H* (*graph*) – A NetworkX graph. *G* and *H* must have the same node sets.

Returns *D*

Return type A new graph with the same type as *G*.

Notes

Attributes from the graph, nodes, and edges are not copied to the new graph. If you want a new graph of the difference of *G* and *H* with with the attributes (including edge data) from *G* use `remove_nodes_from()` as follows:

```
>>> G = nx.path_graph(3)
>>> H = nx.path_graph(5)
>>> R = G.copy()
>>> R.remove_nodes_from(n for n in G if n in H)
```

4.34.8 symmetric_difference

symmetric_difference (*G*, *H*)

Return new graph with edges that exist in either *G* or *H* but not both.

The node sets of *H* and *G* must be the same.

Parameters *G*, *H* (*graph*) – A NetworkX graph. *G* and *H* must have the same node sets.

Returns *D*

Return type A new graph with the same type as *G*.

Notes

Attributes from the graph, nodes, and edges are not copied to the new graph.

Operations on many graphs.

<code>compose_all</code> (graphs[, name])	Return the composition of all graphs.
<code>union_all</code> (graphs[, rename, name])	Return the union of all graphs.
<code>disjoint_union_all</code> (graphs)	Return the disjoint union of all graphs.
<code>intersection_all</code> (graphs)	Return a new graph that contains only the edges that exist in all graphs.

4.34.9 compose_all

compose_all (*graphs*, *name=None*)

Return the composition of all graphs.

Composition is the simple union of the node sets and edge sets. The node sets of the supplied graphs need not be disjoint.

Parameters

- **graphs** (*list*) – List of NetworkX graphs
- **name** (*string*) – Specify name for new graph

Returns C

Return type A graph with the same type as the first graph in list

Notes

It is recommended that the supplied graphs be either all directed or all undirected.

Graph, edge, and node attributes are propagated to the union graph. If a graph attribute is present in multiple graphs, then the value from the last graph in the list with that attribute is used.

4.34.10 union_all

union_all (*graphs*, *rename=(None,)*, *name=None*)

Return the union of all graphs.

The graphs must be disjoint, otherwise an exception is raised.

Parameters

- **graphs** (*list of graphs*) – List of NetworkX graphs
- **rename** (*bool*, *default=(None, None)*) – Node names of G and H can be changed by specifying the tuple `rename=('G-', 'H-')` (for example). Node “u” in G is then renamed “G-u” and “v” in H is renamed “H-v”.
- **name** (*string*) – Specify the name for the union graph@not_implemented_for(‘direct

Returns U

Return type a graph with the same type as the first graph in list

Notes

To force a disjoint union with node relabeling, use `disjoint_union_all(G,H)` or `convert_node_labels_to_integers()`.

Graph, edge, and node attributes are propagated to the union graph. If a graph attribute is present in multiple graphs, then the value from the last graph in the list with that attribute is used.

See also:

`union()`, `disjoint_union_all()`

4.34.11 disjoint_union_all

disjoint_union_all (*graphs*)

Return the disjoint union of all graphs.

This operation forces distinct integer node labels starting with 0 for the first graph in the list and numbering consecutively.

Parameters **graphs** (*list*) – List of NetworkX graphs

Returns **U**

Return type A graph with the same type as the first graph in list

Notes

It is recommended that the graphs be either all directed or all undirected.

Graph, edge, and node attributes are propagated to the union graph. If a graph attribute is present in multiple graphs, then the value from the last graph in the list with that attribute is used.

4.34.12 intersection_all

intersection_all (*graphs*)

Return a new graph that contains only the edges that exist in all graphs.

All supplied graphs must have the same node set.

Parameters **graphs_list** (*list*) – List of NetworkX graphs

Returns **R**

Return type A new graph with the same type as the first graph in list

Notes

Attributes from the graph, nodes, and edges are not copied to the new graph.

Graph products.

<i>cartesian_product</i> (G, H)	Return the Cartesian product of G and H.
<i>lexicographic_product</i> (G, H)	Return the lexicographic product of G and H.
<i>strong_product</i> (G, H)	Return the strong product of G and H.
<i>tensor_product</i> (G, H)	Return the tensor product of G and H.
<i>power</i> (G, k)	Returns the specified power of a graph.

4.34.13 cartesian_product

cartesian_product (*G, H*)

Return the Cartesian product of G and H.

The Cartesian product P of the graphs G and H has a node set that is the Cartesian product of the node sets, $V(P) = V(G) \times V(H)$. P has an edge $((u,v),(x,y))$ if and only if either u is equal to x and v & y are adjacent in H or if v is equal to y and u & x are adjacent in G .

Parameters **H** (*G,*) – Networkx graphs.

Returns **P** – The Cartesian product of G and H. P will be a multi-graph if either G or H is a multi-graph. Will be a directed if G and H are directed, and undirected if G and H are undirected.

Return type NetworkX graph

Raises NetworkXError – If G and H are not both directed or both undirected.

Notes

Node attributes in P are two-tuple of the G and H node attributes. Missing attributes are assigned None.

Examples

```
>>> G = nx.Graph()
>>> H = nx.Graph()
>>> G.add_node(0, a1=True)
>>> H.add_node('a', a2='Spam')
>>> P = nx.cartesian_product(G, H)
>>> P.nodes()
[(0, 'a')]
```

Edge attributes and edge keys (for multigraphs) are also copied to the new product graph

4.34.14 lexicographic_product

lexicographic_product (G, H)

Return the lexicographic product of G and H.

The lexicographical product P of the graphs G and H has a node set that is the Cartesian product of the node sets, $V(P) = V(G) \times V(H)$. P has an edge $((u,v), (x,y))$ if and only if (u,v) is an edge in G or $u=v$ and (x,y) is an edge in H.

Parameters **H** (G,) – Networkx graphs.

Returns **P** – The Cartesian product of G and H. P will be a multi-graph if either G or H is a multi-graph. Will be a directed if G and H are directed, and undirected if G and H are undirected.

Return type NetworkX graph

Raises NetworkXError – If G and H are not both directed or both undirected.

Notes

Node attributes in P are two-tuple of the G and H node attributes. Missing attributes are assigned None.

Examples

```
>>> G = nx.Graph()
>>> H = nx.Graph()
>>> G.add_node(0, a1=True)
>>> H.add_node('a', a2='Spam')
>>> P = nx.lexicographic_product(G, H)
>>> P.nodes()
[(0, 'a')]
```

Edge attributes and edge keys (for multigraphs) are also copied to the new product graph

4.34.15 strong_product

strong_product (*G*, *H*)

Return the strong product of *G* and *H*.

The strong product *P* of the graphs *G* and *H* has a node set that is the Cartesian product of the node sets, $V(P) = V(G) \times V(H)$. *P* has an edge $((u,v),(x,y))$ if and only if $u=x$ and (v,y) is an edge in *H*, or $v=y$ and (u,x) is an edge in *G*, or (u,v) is an edge in *G* and (x,y) is an edge in *H*.

Parameters *H* (*G*,) – NetworkX graphs.

Returns *P* – The Cartesian product of *G* and *H*. *P* will be a multi-graph if either *G* or *H* is a multi-graph. Will be a directed if *G* and *H* are directed, and undirected if *G* and *H* are undirected.

Return type NetworkX graph

Raises `NetworkXError` – If *G* and *H* are not both directed or both undirected.

Notes

Node attributes in *P* are two-tuple of the *G* and *H* node attributes. Missing attributes are assigned None.

Examples

```
>>> G = nx.Graph()
>>> H = nx.Graph()
>>> G.add_node(0, a1=True)
>>> H.add_node('a', a2='Spam')
>>> P = nx.strong_product(G, H)
>>> P.nodes()
[(0, 'a')]
```

Edge attributes and edge keys (for multigraphs) are also copied to the new product graph

4.34.16 tensor_product

tensor_product (*G*, *H*)

Return the tensor product of *G* and *H*.

The tensor product *P* of the graphs *G* and *H* has a node set that is the Cartesian product of the node sets, $V(P) = V(G) \times V(H)$. *P* has an edge $((u,v),(x,y))$ if and only if (u,x) is an edge in *G* and (v,y) is an edge in *H*.

Tensor product is sometimes also referred to as the categorical product, direct product, cardinal product or conjunction.

Parameters *H* (*G*,) – NetworkX graphs.

Returns *P* – The tensor product of *G* and *H*. *P* will be a multi-graph if either *G* or *H* is a multi-graph, will be a directed if *G* and *H* are directed, and undirected if *G* and *H* are undirected.

Return type NetworkX graph

Raises `NetworkXError` – If *G* and *H* are not both directed or both undirected.

Notes

Node attributes in P are two-tuple of the G and H node attributes. Missing attributes are assigned `None`.

Examples

```
>>> G = nx.Graph()
>>> H = nx.Graph()
>>> G.add_node(0, a1=True)
>>> H.add_node('a', a2='Spam')
>>> P = nx.tensor_product(G, H)
>>> P.nodes()
[(0, 'a')]
```

Edge attributes and edge keys (for multigraphs) are also copied to the new product graph

4.34.17 power

power (G, k)

Returns the specified power of a graph.

The k -th power of a simple graph $G = (V, E)$ is the graph G^k whose vertex set is V , two distinct vertices u, v are adjacent in G^k if and only if the shortest path distance between u and v in G is at most k .

Parameters

- **G (graph)** – A NetworkX simple graph object.
- **k (positive integer)** – The power to which to raise the graph G .

Returns G to the k -th power.

Return type NetworkX simple graph

Raises

- **exc:ValueError** – If the exponent k is not positive.
- **NetworkXError** – If G is not a simple graph.

Examples

```
>>> G = nx.path_graph(4)
>>> nx.power(G, 2).edges()
[(0, 1), (0, 2), (1, 2), (1, 3), (2, 3)]
>>> nx.power(G, 3).edges()
[(0, 1), (0, 2), (0, 3), (1, 2), (1, 3), (2, 3)]
```

A complete graph of order n is returned if k is greater than equal to $n/2$ for a cycle graph of even order n , and if k is greater than equal to $(n-1)/2$ for a cycle graph of odd order.

```
>>> G = nx.cycle_graph(5)
>>> nx.power(G, 2).edges() == nx.complete_graph(5).edges()
True
>>> G = nx.cycle_graph(8)
>>> nx.power(G, 4).edges() == nx.complete_graph(8).edges()
True
```

References

Notes

Exercise 3.1.6 of *Graph Theory* by J. A. Bondy and U. S. R. Murty⁶⁰.

4.35 Rich Club

`rich_club_coefficient(G[, normalized, Q])` Return the rich-club coefficient of the graph G.

4.35.1 rich_club_coefficient

rich_club_coefficient (*G*, *normalized=True*, *Q=100*)

Return the rich-club coefficient of the graph G.

The rich-club coefficient is the ratio, for every degree *k*, of the number of actual to the number of potential edges for nodes with degree greater than *k*:

$$\phi(k) = \frac{2Ek}{Nk(Nk - 1)}$$

where *Nk* is the number of nodes with degree larger than *k*, and *Ek* be the number of edges among those nodes.

Parameters

- **G** (*NetworkX graph*) –
- **normalized** (*bool (optional)*) – Normalize using randomized network (see⁶¹)
- **Q** (*float (optional, default=100)*) – If *normalized=True* build a random network by performing *Q***M* double-edge swaps, where *M* is the number of edges in *G*, to use as a null-model for normalization.

Returns **rc** – A dictionary, keyed by degree, with rich club coefficient values.

Return type dictionary

Examples

```
>>> G = nx.Graph([(0,1),(0,2),(1,2),(1,3),(1,4),(4,5)])
>>> rc = nx.rich_club_coefficient(G,normalized=False)
>>> rc[0]
0.4
```

The rich club definition and algorithm are found in¹. This algorithm ignores any edge weights and is not defined for directed graphs or graphs with parallel edges or self loops.

Estimates for appropriate values of *Q* are found in⁶².

⁶⁰

10. (a)Bondy, U. S. R. Murty, *Graph Theory*. Springer, 2008.

⁶¹ Julian J. McAuley, Luciano da Fontoura Costa, and Tib rio S. Caetano, “The rich-club phenomenon across complex network hierarchies”, *Applied Physics Letters* Vol 91 Issue 8, August 2007. <http://arxiv.org/abs/physics/0701290>

⁶² R. Milo, N. Kashtan, S. Itzkovitz, M. E. J. Newman, U. Alon, “Uniform generation of random graphs with arbitrary degree sequences”, 2006. <http://arxiv.org/abs/cond-mat/0312028>

References

4.36 Shortest Paths

Compute the shortest paths and path lengths between nodes in the graph.

These algorithms work with undirected and directed graphs.

<code>shortest_path(G[, source, target, weight])</code>	Compute shortest paths in the graph.
<code>all_shortest_paths(G, source, target[, weight])</code>	Compute all shortest paths in the graph.
<code>shortest_path_length(G[, source, target, weight])</code>	Compute shortest path lengths in the graph.
<code>average_shortest_path_length(G[, weight])</code>	Return the average shortest path length.
<code>has_path(G, source, target)</code>	Return True if G has a path from source to target, False otherwise.

4.36.1 shortest_path

shortest_path (*G, source=None, target=None, weight=None*)

Compute shortest paths in the graph.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node, optional*) – Starting node for path. If not specified, compute shortest paths using all nodes as source nodes.
- **target** (*node, optional*) – Ending node for path. If not specified, compute shortest paths using all nodes as target nodes.
- **weight** (*None or string, optional (default = None)*) – If None, every edge has weight/distance/cost 1. If a string, use this edge attribute as the edge weight. Any edge attribute not present defaults to 1.

Returns

path – All returned paths include both the source and target in the path.

If the source and target are both specified, return a single list of nodes in a shortest path from the source to the target.

If only the source is specified, return a dictionary keyed by targets with a list of nodes in a shortest path from the source to one of the targets.

If only the target is specified, return a dictionary keyed by sources with a list of nodes in a shortest path from one of the sources to the target.

If neither the source nor target are specified return a dictionary of dictionaries with `path[source][target]=[list of nodes in path]`.

Return type list or dictionary

Examples

```
>>> G=nx.path_graph(5)
>>> print(nx.shortest_path(G,source=0,target=4))
[0, 1, 2, 3, 4]
>>> p=nx.shortest_path(G,source=0) # target not specified
```

```
>>> p[4]
[0, 1, 2, 3, 4]
>>> p=nx.shortest_path(G,target=4) # source not specified
>>> p[0]
[0, 1, 2, 3, 4]
>>> p=nx.shortest_path(G) # source,target not specified
>>> p[0][4]
[0, 1, 2, 3, 4]
```

Notes

There may be more than one shortest path between a source and target. This returns only one of them.

See also:

`all_pairs_shortest_path()`, `all_pairs_dijkstra_path()`,
`single_source_shortest_path()`, `single_source_dijkstra_path()`

4.36.2 all_shortest_paths

all_shortest_paths (*G, source, target, weight=None*)

Compute all shortest paths in the graph.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node*) – Starting node for path.
- **target** (*node*) – Ending node for path.
- **weight** (*None or string, optional (default = None)*) – If *None*, every edge has weight/distance/cost 1. If a string, use this edge attribute as the edge weight. Any edge attribute not present defaults to 1.

Returns *paths* – A generator of all paths between source and target.

Return type generator of lists

Examples

```
>>> G=nx.Graph()
>>> G.add_path([0,1,2])
>>> G.add_path([0,10,2])
>>> print([p for p in nx.all_shortest_paths(G, source=0, target=2)])
[[0, 1, 2], [0, 10, 2]]
```

Notes

There may be many shortest paths between the source and target.

See also:

`shortest_path()`, `single_source_shortest_path()`, `all_pairs_shortest_path()`

4.36.3 shortest_path_length

shortest_path_length (*G*, *source=None*, *target=None*, *weight=None*)

Compute shortest path lengths in the graph.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node, optional*) – Starting node for path. If not specified, compute shortest path lengths using all nodes as source nodes.
- **target** (*node, optional*) – Ending node for path. If not specified, compute shortest path lengths using all nodes as target nodes.
- **weight** (*None or string, optional (default = None)*) – If *None*, every edge has weight/distance/cost 1. If a string, use this edge attribute as the edge weight. Any edge attribute not present defaults to 1.

Returns

length – If the source and target are both specified, return the length of the shortest path from the source to the target.

If only the source is specified, return a dictionary keyed by targets whose values are the lengths of the shortest path from the source to one of the targets.

If only the target is specified, return a dictionary keyed by sources whose values are the lengths of the shortest path from one of the sources to the target.

If neither the source nor target are specified return a dictionary of dictionaries with `path[source][target]=L`, where L is the length of the shortest path from source to target.

Return type int or dictionary

Raises `NetworkXNoPath` – If no path exists between source and target.

Examples

```
>>> G=nx.path_graph(5)
>>> print(nx.shortest_path_length(G,source=0,target=4))
4
>>> p=nx.shortest_path_length(G,source=0) # target not specified
>>> p[4]
4
>>> p=nx.shortest_path_length(G,target=4) # source not specified
>>> p[0]
4
>>> p=nx.shortest_path_length(G) # source,target not specified
>>> p[0][4]
4
```

Notes

The length of the path is always 1 less than the number of nodes involved in the path since the length measures the number of edges followed.

For digraphs this returns the shortest directed path length. To find path lengths in the reverse direction use `G.reverse(copy=False)` first to flip the edge orientation.

See also:

`all_pairs_shortest_path_length()`, `all_pairs_dijkstra_path_length()`,
`single_source_shortest_path_length()`, `single_source_dijkstra_path_length()`

4.36.4 average_shortest_path_length

average_shortest_path_length(*G*, *weight=None*)

Return the average shortest path length.

The average shortest path length is

$$a = \sum_{s,t \in V} \frac{d(s,t)}{n(n-1)}$$

where V is the set of nodes in G , $d(s,t)$ is the shortest path from s to t , and n is the number of nodes in G .

Parameters

- **G** (*NetworkX graph*) –
- **weight** (*None or string, optional (default = None)*) – If *None*, every edge has weight/distance/cost 1. If a string, use this edge attribute as the edge weight. Any edge attribute not present defaults to 1.

Raises `NetworkXError` – if the graph is not connected.

Examples

```
>>> G=nx.path_graph(5)
>>> print(nx.average_shortest_path_length(G))
2.0
```

For disconnected graphs you can compute the average shortest path length for each component:

```
>>> G=nx.Graph([(1,2),(3,4)]) >>> for g in nx.connected_component_subgraphs(G): ... print(nx.average_shortest_path_length(g)) 1.0 1.0
```

4.36.5 has_path

has_path(*G*, *source*, *target*)

Return True if G has a path from *source* to *target*, False otherwise.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node*) – Starting node for path
- **target** (*node*) – Ending node for path

4.36.6 Advanced Interface

Shortest path algorithms for unweighted graphs.

<code>single_source_shortest_path(G, source[, cutoff])</code>	Compute shortest path between source and all other nodes reachable
Continued on	

Table 4.88 – continued from previous page

<code>single_source_shortest_path_length(G, source)</code>	Compute the shortest path lengths from source to all reachable nodes
<code>all_pairs_shortest_path(G[, cutoff])</code>	Compute shortest paths between all nodes.
<code>all_pairs_shortest_path_length(G[, cutoff])</code>	Computes the shortest path lengths between all nodes in G.
<code>predecessor(G, source[, target, cutoff, ...])</code>	Returns dictionary of predecessors for the path from source to all nodes

single_source_shortest_path

single_source_shortest_path (*G, source, cutoff=None*)

Compute shortest path between source and all other nodes reachable from source.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node label*) – Starting node for path
- **cutoff** (*integer, optional*) – Depth to stop the search. Only paths of length \leq cutoff are returned.

Returns **lengths** – Dictionary, keyed by target, of shortest paths.

Return type dictionary

Examples

```
>>> G=nx.path_graph(5)
>>> path=nx.single_source_shortest_path(G,0)
>>> path[4]
[0, 1, 2, 3, 4]
```

Notes

The shortest path is not necessarily unique. So there can be multiple paths between the source and each target node, all of which have the same ‘shortest’ length. For each target node, this function returns only one of those paths.

See also:

`shortest_path()`

single_source_shortest_path_length

single_source_shortest_path_length (*G, source, cutoff=None*)

Compute the shortest path lengths from source to all reachable nodes.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node*) – Starting node for path
- **cutoff** (*integer, optional*) – Depth to stop the search. Only paths of length \leq cutoff are returned.

Returns **lengths** – Dictionary of shortest path lengths keyed by target.

Return type dictionary

Examples

```
>>> G=nx.path_graph(5)
>>> length=nx.single_source_shortest_path_length(G,0)
>>> length[4]
4
>>> print(length)
{0: 0, 1: 1, 2: 2, 3: 3, 4: 4}
```

See also:

`shortest_path_length()`

`all_pairs_shortest_path`

`all_pairs_shortest_path`(*G*, *cutoff*=None)

Compute shortest paths between all nodes.

Parameters

- ***G*** (*NetworkX graph*) –
- ***cutoff*** (*integer, optional*) – Depth at which to stop the search. Only paths of length at most *cutoff* are returned.

Returns ***lengths*** – Dictionary, keyed by source and target, of shortest paths.

Return type dictionary

Examples

```
>>> G = nx.path_graph(5)
>>> path = nx.all_pairs_shortest_path(G)
>>> print(path[0][4])
[0, 1, 2, 3, 4]
```

See also:

`floyd_warshall()`

`all_pairs_shortest_path_length`

`all_pairs_shortest_path_length`(*G*, *cutoff*=None)

Computes the shortest path lengths between all nodes in *G*.

Parameters

- ***G*** (*NetworkX graph*) –
- ***cutoff*** (*integer, optional*) – Depth at which to stop the search. Only paths of length at most *cutoff* are returned.

Returns ***lengths*** – Dictionary of shortest path lengths keyed by source and target.

Return type dictionary

Notes

The dictionary returned only has keys for reachable node pairs.

Examples

```
>>> G = nx.path_graph(5)
>>> length = nx.all_pairs_shortest_path_length(G)
>>> print(length[1][4])
3
>>> length[1]
{0: 1, 1: 0, 2: 1, 3: 2, 4: 3}
```

predecessor

predecessor (*G*, *source*, *target=None*, *cutoff=None*, *return_seen=None*)

Returns dictionary of predecessors for the path from source to all nodes in *G*.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node label*) – Starting node for path
- **target** (*node label, optional*) – Ending node for path. If provided only predecessors between source and target are returned
- **cutoff** (*integer, optional*) – Depth to stop the search. Only paths of length \leq cutoff are returned.

Returns **pred** – Dictionary, keyed by node, of predecessors in the shortest path.

Return type dictionary

Examples

```
>>> G=nx.path_graph(4)
>>> print(G.nodes())
[0, 1, 2, 3]
>>> nx.predecessor(G,0)
{0: [], 1: [0], 2: [1], 3: [2]}
```

Shortest path algorithms for weighed graphs.

<code>dijkstra_path(G, source, target[, weight])</code>	Returns the shortest path from source to target in a weighted graph <i>G</i> .
<code>dijkstra_path_length(G, source, target[, weight])</code>	Returns the shortest path length from source to target in a weighted graph <i>G</i> .
<code>single_source_dijkstra_path(G, source[, ...])</code>	Compute shortest path between source and all other reachable nodes in <i>G</i> .
<code>single_source_dijkstra_path_length(G, source)</code>	Compute the shortest path length between source and all other reachable nodes in <i>G</i> .
<code>all_pairs_dijkstra_path(G[, cutoff, weight])</code>	Compute shortest paths between all nodes in a weighted graph <i>G</i> .
<code>all_pairs_dijkstra_path_length(G[, cutoff, ...])</code>	Compute shortest path lengths between all nodes in a weighted graph <i>G</i> .
<code>single_source_dijkstra(G, source[, target, ...])</code>	Compute shortest paths and lengths in a weighted graph <i>G</i> .
<code>bidirectional_dijkstra(G, source, target[, ...])</code>	Dijkstra's algorithm for shortest paths using bidirectional search.
<code>dijkstra_predecessor_and_distance(G, source)</code>	Compute shortest path length and predecessors on shortest paths in weighted graph <i>G</i> .
<code>bellman_ford(G, source[, weight])</code>	Compute shortest path lengths and predecessors on shortest paths in weighted graph <i>G</i> .

Table 4.89 – continued from previous page

<code>negative_edge_cycle(G[, weight])</code>	Return True if there exists a negative edge cycle anywhere in G.
<code>johnson(G[, weight])</code>	Compute shortest paths between all nodes in a weighted graph using

dijkstra_path

dijkstra_path (*G, source, target, weight='weight'*)

Returns the shortest path from source to target in a weighted graph G.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node*) – Starting node
- **target** (*node*) – Ending node
- **weight** (*string, optional (default='weight')*) – Edge data key corresponding to the edge weight

Returns **path** – List of nodes in a shortest path.

Return type `list`

Raises `NetworkXNoPath` – If no path exists between source and target.

Examples

```
>>> G=nx.path_graph(5)
>>> print(nx.dijkstra_path(G,0,4))
[0, 1, 2, 3, 4]
```

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

See also:

`bidirectional_dijkstra()`

dijkstra_path_length

dijkstra_path_length (*G, source, target, weight='weight'*)

Returns the shortest path length from source to target in a weighted graph.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node label*) – starting node for path
- **target** (*node label*) – ending node for path
- **weight** (*string, optional (default='weight')*) – Edge data key corresponding to the edge weight

Returns **length** – Shortest path length.

Return type `number`

Raises `NetworkXNoPath` – If no path exists between source and target.

Examples

```
>>> G=nx.path_graph(5)
>>> print(nx.dijkstra_path_length(G,0,4))
4
```

Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

See also:

`bidirectional_dijkstra()`

single_source_dijkstra_path

single_source_dijkstra_path(*G*, *source*, *cutoff=None*, *weight='weight'*)

Compute shortest path between source and all other reachable nodes for a weighted graph.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node*) – Starting node for path.
- **weight** (*string, optional (default='weight')*) – Edge data key corresponding to the edge weight
- **cutoff** (*integer or float, optional*) – Depth to stop the search. Only paths of length <= cutoff are returned.

Returns **paths** – Dictionary of shortest path lengths keyed by target.

Return type dictionary

Examples

```
>>> G=nx.path_graph(5)
>>> path=nx.single_source_dijkstra_path(G,0)
>>> path[4]
[0, 1, 2, 3, 4]
```

Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

See also:

`single_source_dijkstra()`

single_source_dijkstra_path_length

single_source_dijkstra_path_length(*G*, *source*, *cutoff=None*, *weight='weight'*)

Compute the shortest path length between source and all other reachable nodes for a weighted graph.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node label*) – Starting node for path
- **weight** (*string, optional (default='weight')*) – Edge data key corresponding to the edge weight.
- **cutoff** (*integer or float, optional*) – Depth to stop the search. Only paths of length \leq cutoff are returned.

Returns **length** – Dictionary of shortest lengths keyed by target.

Return type dictionary

Examples

```
>>> G=nx.path_graph(5)
>>> length=nx.single_source_dijkstra_path_length(G,0)
>>> length[4]
4
>>> print(length)
{0: 0, 1: 1, 2: 2, 3: 3, 4: 4}
```

Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

See also:

`single_source_dijkstra()`

all_pairs_dijkstra_path

all_pairs_dijkstra_path(*G, cutoff=None, weight='weight'*)

Compute shortest paths between all nodes in a weighted graph.

Parameters

- **G** (*NetworkX graph*) –
- **weight** (*string, optional (default='weight')*) – Edge data key corresponding to the edge weight
- **cutoff** (*integer or float, optional*) – Depth to stop the search. Only paths of length \leq cutoff are returned.

Returns **distance** – Dictionary, keyed by source and target, of shortest paths.

Return type dictionary

Examples

```
>>> G=nx.path_graph(5)
>>> path=nx.all_pairs_dijkstra_path(G)
>>> print(path[0][4])
[0, 1, 2, 3, 4]
```

Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

See also:

`floyd_warshall()`

`all_pairs_dijkstra_path_length`

`all_pairs_dijkstra_path_length` (*G*, *cutoff=None*, *weight='weight'*)

Compute shortest path lengths between all nodes in a weighted graph.

Parameters

- **G** (*NetworkX graph*) –
- **weight** (*string, optional (default='weight')*) – Edge data key corresponding to the edge weight
- **cutoff** (*integer or float, optional*) – Depth to stop the search. Only paths of length \leq cutoff are returned.

Returns **distance** – Dictionary, keyed by source and target, of shortest path lengths.

Return type dictionary

Examples

```
>>> G=nx.path_graph(5)
>>> length=nx.all_pairs_dijkstra_path_length(G)
>>> print(length[1][4])
3
>>> length[1]
{0: 1, 1: 0, 2: 1, 3: 2, 4: 3}
```

Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

The dictionary returned only has keys for reachable node pairs.

`single_source_dijkstra`

`single_source_dijkstra` (*G*, *source*, *target=None*, *cutoff=None*, *weight='weight'*)

Compute shortest paths and lengths in a weighted graph *G*.

Uses Dijkstra's algorithm for shortest paths.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node label*) – Starting node for path
- **target** (*node label, optional*) – Ending node for path

- **cutoff** (*integer or float, optional*) – Depth to stop the search. Only paths of length \leq cutoff are returned.

Returns **distance,path** – Returns a tuple of two dictionaries keyed by node. The first dictionary stores distance from the source. The second stores the path from the source to that node.

Return type dictionaries

Examples

```
>>> G=nx.path_graph(5)
>>> length,path=nx.single_source_dijkstra(G,0)
>>> print(length[4])
4
>>> print(length)
{0: 0, 1: 1, 2: 2, 3: 3, 4: 4}
>>> path[4]
[0, 1, 2, 3, 4]
```

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

Based on the Python cookbook recipe (119466) at <http://aspn.activestate.com/ASPN/Cookbook/Python/Recipe/119466>

This algorithm is not guaranteed to work if edge weights are negative or are floating point numbers (overflows and roundoff errors can cause problems).

See also:

`single_source_dijkstra_path()`, `single_source_dijkstra_path_length()`

bidirectional_dijkstra

bidirectional_dijkstra (*G, source, target, weight='weight'*)

Dijkstra's algorithm for shortest paths using bidirectional search.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node*) – Starting node.
- **target** (*node*) – Ending node.
- **weight** (*string, optional (default='weight')*) – Edge data key corresponding to the edge weight

Returns

- **length** (*number*) – Shortest path length.
- *Returns a tuple of two dictionaries keyed by node.*
- *The first dictionary stores distance from the source.*
- *The second stores the path from the source to that node.*

Raises `NetworkXNoPath` – If no path exists between source and target.

Examples

```
>>> G=nx.path_graph(5)
>>> length,path=nx.bidirectional_dijkstra(G,0,4)
>>> print(length)
4
>>> print(path)
[0, 1, 2, 3, 4]
```

Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

In practice bidirectional Dijkstra is much more than twice as fast as ordinary Dijkstra.

Ordinary Dijkstra expands nodes in a sphere-like manner from the source. The radius of this sphere will eventually be the length of the shortest path. Bidirectional Dijkstra will expand nodes from both the source and the target, making two spheres of half this radius. Volume of the first sphere is $\pi * r^3$ while the others are $2 * \pi * r^2 * r/2$, making up half the volume.

This algorithm is not guaranteed to work if edge weights are negative or are floating point numbers (overflows and roundoff errors can cause problems).

See also:

`shortest_path()`, `shortest_path_length()`

dijkstra_predecessor_and_distance

dijkstra_predecessor_and_distance (*G*, *source*, *cutoff*=None, *weight*='weight')

Compute shortest path length and predecessors on shortest paths in weighted graphs.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node label*) – Starting node for path
- **weight** (*string, optional (default='weight')*) – Edge data key corresponding to the edge weight
- **cutoff** (*integer or float, optional*) – Depth to stop the search. Only paths of length \leq cutoff are returned.

Returns **pred,distance** – Returns two dictionaries representing a list of predecessors of a node and the distance to each node.

Return type dictionaries

Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

The list of predecessors contains more than one element only when there are more than one shortest paths to the key node.

bellman_ford

bellman_ford(*G*, *source*, *weight*='weight')

Compute shortest path lengths and predecessors on shortest paths in weighted graphs.

The algorithm has a running time of $O(mn)$ where n is the number of nodes and m is the number of edges. It is slower than Dijkstra but can handle negative edge weights.

Parameters

- **G** (*NetworkX graph*) – The algorithm works for all types of graphs, including directed graphs and multigraphs.
- **source** (*node label*) – Starting node for path
- **weight** (*string, optional (default='weight')*) – Edge data key corresponding to the edge weight

Returns **pred, dist** – Returns two dictionaries keyed by node to predecessor in the path and to the distance from the source respectively.

Return type dictionaries

Raises `NetworkXUnbounded` – If the (di)graph contains a negative cost (di)cycle, the algorithm raises an exception to indicate the presence of the negative cost (di)cycle. Note: any negative weight edge in an undirected graph is a negative cost cycle.

Examples

```
>>> import networkx as nx
>>> G = nx.path_graph(5, create_using = nx.DiGraph())
>>> pred, dist = nx.bellman_ford(G, 0)
>>> sorted(pred.items())
[(0, None), (1, 0), (2, 1), (3, 2), (4, 3)]
>>> sorted(dist.items())
[(0, 0), (1, 1), (2, 2), (3, 3), (4, 4)]
```

```
>>> from nose.tools import assert_raises
>>> G = nx.cycle_graph(5, create_using = nx.DiGraph())
>>> G[1][2]['weight'] = -7
>>> assert_raises(nx.NetworkXUnbounded, nx.bellman_ford, G, 0)
```

Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

The dictionaries returned only have keys for nodes reachable from the source.

In the case where the (di)graph is not connected, if a component not containing the source contains a negative cost (di)cycle, it will not be detected.

negative_edge_cycle

negative_edge_cycle(*G*, *weight*='weight')

Return True if there exists a negative edge cycle anywhere in *G*.

Parameters

- **G** (*NetworkX graph*) –
- **weight** (*string, optional (default='weight')*) – Edge data key corresponding to the edge weight

Returns **negative_cycle** – True if a negative edge cycle exists, otherwise False.

Return type `bool`

Examples

```
>>> import networkx as nx
>>> G = nx.cycle_graph(5, create_using = nx.DiGraph())
>>> print(nx.negative_edge_cycle(G))
False
>>> G[1][2]['weight'] = -7
>>> print(nx.negative_edge_cycle(G))
True
```

Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

This algorithm uses `bellman_ford()` but finds negative cycles on any component by first adding a new node connected to every node, and starting `bellman_ford` on that node. It then removes that extra node.

johnson

johnson (*G, weight='weight'*)

Compute shortest paths between all nodes in a weighted graph using Johnson's algorithm.

Parameters

- **G** (*NetworkX graph*) –
- **weight** (*string, optional (default='weight')*) – Edge data key corresponding to the edge weight.

Returns **distance** – Dictionary, keyed by source and target, of shortest paths.

Return type `dictionary`

Raises `NetworkXError` – If given graph is not weighted.

Examples

```
>>> import networkx as nx
>>> graph = nx.DiGraph()
>>> graph.add_weighted_edges_from([('0', '3', 3), ('0', '1', -5),
... ('0', '2', 2), ('1', '2', 4), ('2', '3', 1)])
>>> paths = nx.johnson(graph, weight='weight')
>>> paths['0']['2']
['0', '1', '2']
```

Johnson's algorithm is suitable even for graphs with negative weights. It works by using the Bellman–Ford algorithm to compute a transformation of the input graph that removes all negative weights, allowing Dijkstra's algorithm to be used on the transformed graph.

It may be faster than Floyd - Warshall algorithm in sparse graphs. Algorithm complexity: $O(V^2 * \log V + V * E)$

See also:

```
floyd_warshall_predecessor_and_distance(), floyd_warshall_numpy(),
all_pairs_shortest_path(), all_pairs_shortest_path_length(),
all_pairs_dijkstra_path(), bellman_ford()
```

4.36.7 Dense Graphs

Floyd-Warshall algorithm for shortest paths.

<code>floyd_warshall(G[, weight])</code>	Find all-pairs shortest path lengths using Floyd's algorithm.
<code>floyd_warshall_predecessor_and_distance(G[, ...])</code>	Find all-pairs shortest path lengths using Floyd's algorithm.
<code>floyd_warshall_numpy(G[, nodelist, weight])</code>	Find all-pairs shortest path lengths using Floyd's algorithm.

floyd_warshall

floyd_warshall (*G*, *weight*='weight')

Find all-pairs shortest path lengths using Floyd's algorithm.

Parameters

- **G** (*NetworkX graph*) –
- **weight** (*string, optional (default= 'weight')*) – Edge data key corresponding to the edge weight.

Returns

- **distance** (*dict*) – A dictionary, keyed by source and target, of shortest paths distances between nodes.
- *Notes*
- —
- *Floyd's algorithm is appropriate for finding shortest paths*
- *in dense graphs or graphs with negative weights when Dijkstra's algorithm*
- *fails. This algorithm can still fail if there are negative cycles.*
- *It has running time $O(n^3)$ with running space of $O(n^2)$.*

See also:

```
floyd_warshall_predecessor_and_distance(), floyd_warshall_numpy(),
all_pairs_shortest_path(), all_pairs_shortest_path_length()
```

floyd_warshall_predecessor_and_distance

floyd_warshall_predecessor_and_distance (*G*, *weight*='weight')

Find all-pairs shortest path lengths using Floyd's algorithm.

Parameters

- **G** (*NetworkX graph*) –
- **weight** (*string, optional (default= 'weight')*) – Edge data key corresponding to the edge weight.

Returns

- **predecessor,distance** (*dictionaries*) – Dictionaries, keyed by source and target, of predecessors and distances in the shortest path.
- *Notes*
- —
- *Floyd's algorithm is appropriate for finding shortest paths*
- *in dense graphs or graphs with negative weights when Dijkstra's algorithm*
- *fails. This algorithm can still fail if there are negative cycles.*
- *It has running time $O(n^3)$ with running space of $O(n^2)$.*

See also:

`floyd_warshall()`, `floyd_warshall_numpy()`, `all_pairs_shortest_path()`,
`all_pairs_shortest_path_length()`

floyd_warshall_numpy

floyd_warshall_numpy (*G, nodelist=None, weight='weight'*)

Find all-pairs shortest path lengths using Floyd's algorithm.

Parameters

- **G** (*NetworkX graph*) –
- **nodelist** (*list, optional*) – The rows and columns are ordered by the nodes in nodelist. If nodelist is None then the ordering is produced by `G.nodes()`.
- **weight** (*string, optional (default= 'weight')*) – Edge data key corresponding to the edge weight.

Returns

- **distance** (*NumPy matrix*) – A matrix of shortest path distances between nodes. If there is no path between to nodes the corresponding matrix entry will be Inf.
- *Notes*
- —
- *Floyd's algorithm is appropriate for finding shortest paths in*
- *dense graphs or graphs with negative weights when Dijkstra's*
- *algorithm fails. This algorithm can still fail if there are*
- *negative cycles. It has running time $O(n^3)$ with running space of $O(n^2)$.*

4.36.8 A* Algorithm

Shortest paths and path lengths using A* ("A star") algorithm.

<code>astar_path(G, source, target[, heuristic, ...])</code>	Return a list of nodes in a shortest path between source and target using the A* (“A-star”) algorithm.
<code>astar_path_length(G, source, target[, ...])</code>	Return the length of the shortest path between source and target using the A* (“A-star”) algorithm.

astar_path

astar_path (*G*, *source*, *target*, *heuristic=None*, *weight='weight'*)

Return a list of nodes in a shortest path between source and target using the A* (“A-star”) algorithm.

There may be more than one shortest path. This returns only one.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node*) – Starting node for path
- **target** (*node*) – Ending node for path
- **heuristic** (*function*) – A function to evaluate the estimate of the distance from the a node to the target. The function takes two nodes arguments and must return a number.
- **weight** (*string, optional (default='weight')*) – Edge data key corresponding to the edge weight.

Raises `NetworkXNoPath` – If no path exists between source and target.

Examples

```
>>> G=nx.path_graph(5)
>>> print(nx.astar_path(G,0,4))
[0, 1, 2, 3, 4]
>>> G=nx.grid_graph(dim=[3,3]) # nodes are two-tuples (x,y)
>>> def dist(a, b):
...     (x1, y1) = a
...     (x2, y2) = b
...     return ((x1 - x2) ** 2 + (y1 - y2) ** 2) ** 0.5
>>> print(nx.astar_path(G, (0,0), (2,2), dist))
[(0, 0), (0, 1), (1, 1), (1, 2), (2, 2)]
```

See also:

`shortest_path()`, `dijkstra_path()`

astar_path_length

astar_path_length (*G*, *source*, *target*, *heuristic=None*, *weight='weight'*)

Return the length of the shortest path between source and target using the A* (“A-star”) algorithm.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node*) – Starting node for path
- **target** (*node*) – Ending node for path
- **heuristic** (*function*) – A function to evaluate the estimate of the distance from the a node to the target. The function takes two nodes arguments and must return a number.

Raises `NetworkXNoPath` – If no path exists between source and target.

See also:

`astar_path()`

4.37 Simple Paths

<code>all_simple_paths(G, source, target[, cutoff])</code>	Generate all simple paths in the graph G from source to target.
<code>shortest_simple_paths(G, source, target[, ...])</code>	Generate all simple paths in the graph G from source to target, starting from

4.37.1 all_simple_paths

all_simple_paths (*G, source, target, cutoff=None*)

Generate all simple paths in the graph G from source to target.

A simple path is a path with no repeated nodes.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node*) – Starting node for path
- **target** (*node*) – Ending node for path
- **cutoff** (*integer, optional*) – Depth to stop the search. Only paths of length \leq cutoff are returned.

Returns `path_generator` – A generator that produces lists of simple paths. If there are no paths between the source and target within the given cutoff the generator produces no output.

Return type generator

Examples

```
>>> G = nx.complete_graph(4)
>>> for path in nx.all_simple_paths(G, source=0, target=3):
...     print(path)
...
[0, 1, 2, 3]
[0, 1, 3]
[0, 2, 1, 3]
[0, 2, 3]
[0, 3]
>>> paths = nx.all_simple_paths(G, source=0, target=3, cutoff=2)
>>> print(list(paths))
[[0, 1, 3], [0, 2, 3], [0, 3]]
```

Notes

This algorithm uses a modified depth-first search to generate the paths⁶³. A single path can be found in $O(V + E)$ time but the number of simple paths in a graph can be very large, e.g. $O(n!)$ in the complete graph of order

⁶³ R. Sedgewick, “Algorithms in C, Part 5: Graph Algorithms”, Addison Wesley Professional, 3rd ed., 2001.

n.

References

See also:

`all_shortest_paths()`, `shortest_path()`

4.37.2 `shortest_simple_paths`

`shortest_simple_paths` (*G*, *source*, *target*, *weight=None*)

Generate all simple paths in the graph **G** from **source** to **target**, starting from shortest ones.

A simple path is a path with no repeated nodes.

If a weighted shortest path search is to be used, no negative weights are allowed.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node*) – Starting node for path
- **target** (*node*) – Ending node for path
- **weight** (*string*) – Name of the edge attribute to be used as a weight. If None all edges are considered to have unit weight. Default value None.

Returns **path_generator** – A generator that produces lists of simple paths, in order from shortest to longest.

Return type generator

Raises

- `NetworkXNoPath` – If no path exists between source and target.
- `NetworkXError` – If source or target nodes are not in the input graph.
- `NetworkXNotImplemented` – If the input graph is a `Multi[Di]Graph`.

Examples

```
>>> G = nx.cycle_graph(7)
>>> paths = list(nx.shortest_simple_paths(G, 0, 3))
>>> print(paths)
[[0, 1, 2, 3], [0, 6, 5, 4, 3]]
```

You can use this function to efficiently compute the k shortest/best paths between two nodes.

```
>>> from itertools import islice
>>> def k_shortest_paths(G, source, target, k, weight=None):
...     return list(islice(nx.shortest_simple_paths(G, source, target, weight=weight), k))
>>> for path in k_shortest_paths(G, 0, 3, 2):
...     print(path)
[0, 1, 2, 3]
[0, 6, 5, 4, 3]
```

Notes

This procedure is based on algorithm by Jin Y. Yen⁶⁴. Finding the first K paths requires $O(KN^3)$ operations.

See also:

`all_shortest_paths()`, `shortest_path()`, `all_simple_paths()`

References

4.38 Swap

Swap edges in a graph.

<code>double_edge_swap(G[, nswap, max_tries])</code>	Swap two edges in the graph while keeping the node degrees fixed.
<code>connected_double_edge_swap(G[, nswap, ...])</code>	Attempts the specified number of double-edge swaps in the graph G.

4.38.1 double_edge_swap

double_edge_swap (*G*, *nswap*=1, *max_tries*=100)

Swap two edges in the graph while keeping the node degrees fixed.

A double-edge swap removes two randomly chosen edges *u-v* and *x-y* and creates the new edges *u-x* and *v-y*:

<i>u-v</i>		<i>u</i>	<i>v</i>
	becomes		
<i>x-y</i>		<i>x</i>	<i>y</i>

If either the edge *u-x* or *v-y* already exist no swap is performed and another attempt is made to find a suitable edge pair.

Parameters

- **G** (*graph*) – An undirected graph
- **nswap** (*integer (optional, default=1)*) – Number of double-edge swaps to perform
- **max_tries** (*integer (optional)*) – Maximum number of attempts to swap edges

Returns **G** – The graph after double edge swaps.

Return type graph

Notes

Does not enforce any connectivity constraints.

The graph *G* is modified in place.

⁶⁴ Jin Y. Yen, "Finding the K Shortest Loopless Paths in a Network", Management Science, Vol. 17, No. 11, Theory Series (Jul., 1971), pp. 712-716.

4.38.2 connected_double_edge_swap

connected_double_edge_swap (*G*, *nswap*=1, *_window_threshold*=3)

Attempts the specified number of double-edge swaps in the graph *G*.

A double-edge swap removes two randomly chosen edges (*u*, *v*) and (*x*, *y*) and creates the new edges (*u*, *x*) and (*v*, *y*):

<i>u</i> -- <i>v</i>		<i>u</i>	<i>v</i>
	becomes		
<i>x</i> -- <i>y</i>		<i>x</i>	<i>y</i>

If either (*u*, *x*) or (*v*, *y*) already exist, then no swap is performed so the actual number of swapped edges is always *at most* *nswap*.

Parameters

- **G** (*graph*) – An undirected graph
- **nswap** (*integer (optional, default=1)*) – Number of double-edge swaps to perform
- **_window_threshold** (*integer*) – The window size below which connectedness of the graph will be checked after each swap.

The “window” in this function is a dynamically updated integer that represents the number of swap attempts to make before checking if the graph remains connected. It is an optimization used to decrease the running time of the algorithm in exchange for increased complexity of implementation.

If the window size is below this threshold, then the algorithm checks after each swap if the graph remains connected by checking if there is a path joining the two nodes whose edge was just removed. If the window size is above this threshold, then the algorithm performs do all the swaps in the window and only then check if the graph is still connected.

Returns The number of successful swaps

Return type `int`

Raises `NetworkXError` –

If the input graph is not connected, or if the graph has fewer than four nodes.

Notes

The initial graph *G* must be connected, and the resulting graph is connected. The graph *G* is modified in place.

References

4.39 Traversal

4.39.1 Depth First Search

Depth-first search

Basic algorithms for depth-first searching the nodes of a graph.

Based on <http://www.ics.uci.edu/~eppstein/PADS/DFS.py> by D. Eppstein, July 2004.

<code>dfs_edges(G[, source])</code>	Produce edges in a depth-first-search (DFS).
<code>dfs_tree(G, source)</code>	Return oriented tree constructed from a depth-first-search from source.
<code>dfs_predecessors(G[, source])</code>	Return dictionary of predecessors in depth-first-search from source.
<code>dfs_successors(G[, source])</code>	Return dictionary of successors in depth-first-search from source.
<code>dfs_preorder_nodes(G[, source])</code>	Produce nodes in a depth-first-search pre-ordering starting from source.
<code>dfs_postorder_nodes(G[, source])</code>	Produce nodes in a depth-first-search post-ordering starting from source.
<code>dfs_labeled_edges(G[, source])</code>	Produce edges in a depth-first-search (DFS) labeled by type.

dfs_edges

dfs_edges (*G*, *source=None*)

Produce edges in a depth-first-search (DFS).

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node, optional*) – Specify starting node for depth-first search and return edges in the component reachable from source.

Returns **edges** – A generator of edges in the depth-first-search.

Return type generator

Examples

```
>>> G = nx.Graph()
>>> G.add_path([0,1,2])
>>> print(list(nx.dfs_edges(G,0)))
[(0, 1), (1, 2)]
```

Notes

Based on <http://www.ics.uci.edu/~eppstein/PADS/DFS.py> by D. Eppstein, July 2004.

If a source is not specified then a source is chosen arbitrarily and repeatedly until all components in the graph are searched.

dfs_tree

dfs_tree (*G*, *source*)

Return oriented tree constructed from a depth-first-search from source.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node, optional*) – Specify starting node for depth-first search.

Returns **T** – An oriented tree

Return type NetworkX DiGraph

Examples

```
>>> G = nx.Graph()
>>> G.add_path([0,1,2])
>>> T = nx.dfs_tree(G,0)
>>> print(T.edges())
[(0, 1), (1, 2)]
```

dfs_predecessors

dfs_predecessors (*G*, *source=None*)

Return dictionary of predecessors in depth-first-search from source.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node, optional*) – Specify starting node for depth-first search and return edges in the component reachable from source.

Returns **pred** – A dictionary with nodes as keys and predecessor nodes as values.

Return type **dict**

Examples

```
>>> G = nx.Graph()
>>> G.add_path([0,1,2])
>>> print(nx.dfs_predecessors(G,0))
{1: 0, 2: 1}
```

Notes

Based on <http://www.ics.uci.edu/~eppstein/PADS/DFS.py> by D. Eppstein, July 2004.

If a source is not specified then a source is chosen arbitrarily and repeatedly until all components in the graph are searched.

dfs_successors

dfs_successors (*G*, *source=None*)

Return dictionary of successors in depth-first-search from source.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node, optional*) – Specify starting node for depth-first search and return edges in the component reachable from source.

Returns **succ** – A dictionary with nodes as keys and list of successor nodes as values.

Return type **dict**

Examples

```
>>> G = nx.Graph()
>>> G.add_path([0,1,2])
>>> print(nx.dfs_successors(G,0))
{0: [1], 1: [2]}
```

Notes

Based on <http://www.ics.uci.edu/~eppstein/PADS/DFS.py> by D. Eppstein, July 2004.

If a source is not specified then a source is chosen arbitrarily and repeatedly until all components in the graph are searched.

dfs_preorder_nodes

dfs_preorder_nodes (*G*, *source=None*)

Produce nodes in a depth-first-search pre-ordering starting from source.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node, optional*) – Specify starting node for depth-first search and return edges in the component reachable from source.

Returns **nodes** – A generator of nodes in a depth-first-search pre-ordering.

Return type generator

Examples

```
>>> G = nx.Graph()
>>> G.add_path([0,1,2])
>>> print(list(nx.dfs_preorder_nodes(G,0)))
[0, 1, 2]
```

Notes

Based on <http://www.ics.uci.edu/~eppstein/PADS/DFS.py> by D. Eppstein, July 2004.

If a source is not specified then a source is chosen arbitrarily and repeatedly until all components in the graph are searched.

dfs_postorder_nodes

dfs_postorder_nodes (*G*, *source=None*)

Produce nodes in a depth-first-search post-ordering starting from source.

Parameters

- **G** (*NetworkX graph*) –

- **source** (*node, optional*) – Specify starting node for depth-first search and return edges in the component reachable from source.

Returns **nodes** – A generator of nodes in a depth-first-search post-ordering.

Return type generator

Examples

```
>>> G = nx.Graph()
>>> G.add_path([0,1,2])
>>> print(list(nx.dfs_postorder_nodes(G,0)))
[2, 1, 0]
```

Notes

Based on <http://www.ics.uci.edu/~eppstein/PADS/DFS.py> by D. Eppstein, July 2004.

If a source is not specified then a source is chosen arbitrarily and repeatedly until all components in the graph are searched.

dfs_labeled_edges

dfs_labeled_edges (*G, source=None*)

Produce edges in a depth-first-search (DFS) labeled by type.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node, optional*) – Specify starting node for depth-first search and return edges in the component reachable from source.

Returns **edges** – A generator of edges in the depth-first-search labeled with ‘forward’, ‘nontree’, and ‘reverse’.

Return type generator

Examples

```
>>> G = nx.Graph()
>>> G.add_path([0,1,2])
>>> edges = (list(nx.dfs_labeled_edges(G,0)))
```

Notes

Based on <http://www.ics.uci.edu/~eppstein/PADS/DFS.py> by D. Eppstein, July 2004.

If a source is not specified then a source is chosen arbitrarily and repeatedly until all components in the graph are searched.

4.39.2 Breadth First Search

Breadth-first search

Basic algorithms for breadth-first searching the nodes of a graph.

<code>bfs_edges(G, source[, reverse])</code>	Produce edges in a breadth-first-search starting at source.
<code>bfs_tree(G, source[, reverse])</code>	Return an oriented tree constructed from of a breadth-first-search starting at source.
<code>bfs_predecessors(G, source)</code>	Return dictionary of predecessors in breadth-first-search from source.
<code>bfs_successors(G, source)</code>	Return dictionary of successors in breadth-first-search from source.

bfs_edges

bfs_edges (*G*, *source*, *reverse=False*)

Produce edges in a breadth-first-search starting at source.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node*) – Specify starting node for breadth-first search and return edges in the component reachable from source.
- **reverse** (*bool, optional*) – If True traverse a directed graph in the reverse direction

Returns **edges** – A generator of edges in the breadth-first-search.

Return type generator

Examples

```
>>> G = nx.Graph()
>>> G.add_path([0,1,2])
>>> print(list(nx.bfs_edges(G,0)))
[(0, 1), (1, 2)]
```

Notes

Based on <http://www.ics.uci.edu/~eppstein/PADS/BFS.py> by D. Eppstein, July 2004.

bfs_tree

bfs_tree (*G*, *source*, *reverse=False*)

Return an oriented tree constructed from of a breadth-first-search starting at source.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node*) – Specify starting node for breadth-first search and return edges in the component reachable from source.
- **reverse** (*bool, optional*) – If True traverse a directed graph in the reverse direction

Returns **T** – An oriented tree

Return type NetworkX DiGraph

Examples

```
>>> G = nx.Graph()
>>> G.add_path([0,1,2])
>>> print(list(nx.bfs_edges(G,0)))
[(0, 1), (1, 2)]
```

Notes

Based on <http://www.ics.uci.edu/~eppstein/PADS/BFS.py> by D. Eppstein, July 2004.

bfs_predecessors

bfs_predecessors (*G*, *source*)

Return dictionary of predecessors in breadth-first-search from source.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node*) – Specify starting node for breadth-first search and return edges in the component reachable from source.

Returns **pred** – A dictionary with nodes as keys and predecessor nodes as values.

Return type dict

Examples

```
>>> G = nx.Graph()
>>> G.add_path([0,1,2])
>>> print(nx.bfs_predecessors(G,0))
{1: 0, 2: 1}
```

Notes

Based on <http://www.ics.uci.edu/~eppstein/PADS/BFS.py> by D. Eppstein, July 2004.

bfs_successors

bfs_successors (*G*, *source*)

Return dictionary of successors in breadth-first-search from source.

Parameters

- **G** (*NetworkX graph*) –
- **source** (*node*) – Specify starting node for breadth-first search and return edges in the component reachable from source.

Returns **succ** – A dictionary with nodes as keys and list of successors nodes as values.

Return type dict

Examples

```
>>> G = nx.Graph()
>>> G.add_path([0,1,2])
>>> print(nx.bfs_successors(G,0))
{0: [1], 1: [2]}
```

Notes

Based on <http://www.ics.uci.edu/~eppstein/PADS/BFS.py> by D. Eppstein, July 2004.

4.39.3 Depth First Search on Edges

Depth First Search on Edges

Algorithms for a depth-first traversal of edges in a graph.

`edge_dfs(G[, source, orientation])` A directed, depth-first traversal of edges in G, beginning at *source*.

edge_dfs

edge_dfs (*G*, *source*=None, *orientation*='original')

A directed, depth-first traversal of edges in G, beginning at *source*.

Parameters

- **G** (*graph*) – A directed/undirected graph/multigraph.
- **source** (*node*, *list of nodes*) – The node from which the traversal begins. If None, then a source is chosen arbitrarily and repeatedly until all edges from each node in the graph are searched.
- **orientation** ('original' | 'reverse' | 'ignore') – For directed graphs and directed multigraphs, edge traversals need not respect the original orientation of the edges. When set to 'reverse', then every edge will be traversed in the reverse direction. When set to 'ignore', then each directed edge is treated as a single undirected edge that can be traversed in either direction. For undirected graphs and undirected multigraphs, this parameter is meaningless and is not consulted by the algorithm.

Yields **edge** (*directed edge*) – A directed edge indicating the path taken by the depth-first traversal.

For graphs, edge is of the form (*u*, *v*) where *u* and *v* are the tail and head of the edge as determined by the traversal. For multigraphs, edge is of the form (*u*, *v*, *key*), where *key* is the key of the edge. When the graph is directed, then *u* and *v* are always in the order of the actual directed edge. If orientation is 'reverse' or 'ignore', then edge takes the form (*u*, *v*, *key*, *direction*) where *direction* is a string, 'forward' or 'reverse', that indicates if the edge was traversed in the forward (tail to head) or reverse (head to tail) direction, respectively.

Examples

```
>>> import networkx as nx
>>> nodes = [0, 1, 2, 3]
>>> edges = [(0, 1), (1, 0), (1, 0), (2, 1), (3, 1)]
```

```
>>> list(nx.edge_dfs(nx.Graph(edges), nodes))
[(0, 1), (1, 2), (1, 3)]
```

```
>>> list(nx.edge_dfs(nx.DiGraph(edges), nodes))
[(0, 1), (1, 0), (2, 1), (3, 1)]
```

```
>>> list(nx.edge_dfs(nx.MultiGraph(edges), nodes))
[(0, 1, 0), (1, 0, 1), (0, 1, 2), (1, 2, 0), (1, 3, 0)]
```

```
>>> list(nx.edge_dfs(nx.MultiDiGraph(edges), nodes))
[(0, 1, 0), (1, 0, 0), (1, 0, 1), (2, 1, 0), (3, 1, 0)]
```

```
>>> list(nx.edge_dfs(nx.DiGraph(edges), nodes, orientation='ignore'))
[(0, 1, 'forward'), (1, 0, 'forward'), (2, 1, 'reverse'), (3, 1, 'reverse')]
```

```
>>> list(nx.edge_dfs(nx.MultiDiGraph(edges), nodes, orientation='ignore'))
[(0, 1, 0, 'forward'), (1, 0, 0, 'forward'), (1, 0, 1, 'reverse'), (2, 1, 0, 'reverse'), (3, 1,
```

Notes

The goal of this function is to visit edges. It differs from the more familiar depth-first traversal of nodes, as provided by `networkx.algorithms.traversal.depth_first_search.dfs_edges()`, in that it does not stop once every node has been visited. In a directed graph with edges `[(0, 1), (1, 2), (2, 1)]`, the edge `(2, 1)` would not be visited if not for the functionality provided by this function.

See also:

`dfs_edges()`

4.40 Tree

4.40.1 Recognition

Recognition Tests

A *forest* is an acyclic, undirected graph, and a *tree* is a connected forest. Depending on the subfield, there are various conventions for generalizing these definitions to directed graphs.

In one convention, directed variants of forest and tree are defined in an identical manner, except that the direction of the edges is ignored. In effect, each directed edge is treated as a single undirected edge. Then, additional restrictions are imposed to define *branchings* and *arborescences*.

In another convention, directed variants of forest and tree correspond to the previous convention's branchings and arborescences, respectively. Then two new terms, *polyforest* and *polytree*, are defined to correspond to the other convention's forest and tree.

Summarizing:

Convention A	Convention B
forest	polyforest
tree	polytree
branching	forest
arborescence	tree

Each convention has its reasons. The first convention emphasizes definitional similarity in that directed forests and trees are only concerned with acyclicity and do not have an in-degree constraint, just as their undirected counterparts do not. The second convention emphasizes functional similarity in the sense that the directed analog of a spanning tree is a spanning arborescence. That is, take any spanning tree and choose one node as the root. Then every edge is assigned a direction such there is a directed path from the root to every other node. The result is a spanning arborescence.

NetworkX follows convention “A”. Explicitly, these are:

undirected forest An undirected graph with no undirected cycles.

undirected tree A connected, undirected forest.

directed forest A directed graph with no undirected cycles. Equivalently, the underlying graph structure (which ignores edge orientations) is an undirected forest. In convention B, this is known as a polyforest.

directed tree A weakly connected, directed forest. Equivalently, the underlying graph structure (which ignores edge orientations) is an undirected tree. In convention B, this is known as a polytree.

branching A directed forest with each node having, at most, one parent. So the maximum in-degree is equal to 1. In convention B, this is known as a forest.

arborescence A directed tree with each node having, at most, one parent. So the maximum in-degree is equal to 1. In convention B, this is known as a tree.

For trees and arborescences, the adjective “spanning” may be added to designate that the graph, when considered as a forest/branching, consists of a single tree/arborescence that includes all nodes in the graph. It is true, by definition, that every tree/arborescence is spanning with respect to the nodes that define the tree/arborescence and so, it might seem redundant to introduce the notion of “spanning”. However, the nodes may represent a subset of nodes from a larger graph, and it is in this context that the term “spanning” becomes a useful notion.

<code>is_tree(G)</code>	Returns True if G is a tree.
<code>is_forest(G)</code>	Returns True if G is a forest.
<code>is_arborescence(G)</code>	Returns True if G is an arborescence.
<code>is_branching(G)</code>	Returns True if G is a branching.

is_tree

is_tree(G)

Returns True if G is a tree.

A tree is a connected graph with no undirected cycles.

For directed graphs, G is a tree if the underlying graph is a tree. The underlying graph is obtained by treating each directed edge as a single undirected edge in a multigraph.

Parameters *G* (*graph*) – The graph to test.

Returns *b* – A boolean that is True if G is a tree.

Return type bool

Notes

In another convention, a directed tree is known as a *polytree* and then *tree* corresponds to an *arborescence*.

See also:

`is_arborescence()`

is_forest

is_forest (*G*)

Returns `True` if *G* is a forest.

A forest is a graph with no undirected cycles.

For directed graphs, *G* is a forest if the underlying graph is a forest. The underlying graph is obtained by treating each directed edge as a single undirected edge in a multigraph.

Parameters *G* (*graph*) – The graph to test.

Returns *b* – A boolean that is `True` if *G* is a forest.

Return type `bool`

Notes

In another convention, a directed forest is known as a *polyforest* and then *forest* corresponds to a *branching*.

See also:

`is_branching()`

is_arborescence

is_arborescence (*G*)

Returns `True` if *G* is an arborescence.

An arborescence is a directed tree with maximum in-degree equal to 1.

Parameters *G* (*graph*) – The graph to test.

Returns *b* – A boolean that is `True` if *G* is an arborescence.

Return type `bool`

Notes

In another convention, an arborescence is known as a *tree*.

See also:

`is_tree()`

is_branching

is_branching(*G*)

Returns True if *G* is a branching.

A branching is a directed forest with maximum in-degree equal to 1.

Parameters *G* (*directed graph*) – The directed graph to test.

Returns *b* – A boolean that is True if *G* is a branching.

Return type bool

Notes

In another convention, a branching is also known as a *forest*.

See also:

`is_forest()`

4.40.2 Branchings and Spanning Arborescences

Algorithms for finding optimum branchings and spanning arborescences.

This implementation is based on:

J. Edmonds, Optimum branchings, J. Res. Natl. Bur. Standards 71B (1967), 233–240. URL:
<http://archive.org/details/jresv71Bn4p233>

<code>branching_weight(G[, attr, default])</code>	Returns the total weight of a branching.
<code>greedy_branching(G[, attr, default, kind])</code>	Returns a branching obtained through a greedy algorithm.
<code>maximum_branching(G[, attr, default])</code>	Returns a maximum branching from <i>G</i> .
<code>minimum_branching(G[, attr, default])</code>	Returns a minimum branching from <i>G</i> .
<code>maximum_spanning_arborescence(G[, attr, default])</code>	Returns a maximum spanning arborescence from <i>G</i> .
<code>minimum_spanning_arborescence(G[, attr, default])</code>	Returns a minimum spanning arborescence from <i>G</i> .
<code>Edmonds(G[, seed])</code>	Edmonds algorithm for finding optimal branchings and spanning arborescences.

branching_weight

branching_weight(*G*, *attr*=*'weight'*, *default*=1)

Returns the total weight of a branching.

greedy_branching

greedy_branching(*G*, *attr*=*'weight'*, *default*=1, *kind*=*'max'*)

Returns a branching obtained through a greedy algorithm.

This algorithm is wrong, and cannot give a proper optimal branching. However, we include it for pedagogical reasons, as it can be helpful to see what its outputs are.

The output is a branching, and possibly, a spanning arborescence. However, it is not guaranteed to be optimal in either case.

Parameters

- **G** (*DiGraph*) – The directed graph to scan.
- **attr** (*str*) – The attribute to use as weights. If *None*, then each edge will be treated equally with a weight of 1.
- **default** (*float*) – When *attr* is not *None*, then if an edge does not have that attribute, *default* specifies what value it should take.
- **kind** (*str*) – The type of optimum to search for: ‘min’ or ‘max’ greedy branching.

Returns **B** – The greedily obtained branching.

Return type directed graph

maximum_branching

maximum_branching (*G*, *attr*=‘weight’, *default*=1)

Returns a maximum branching from *G*.

Parameters

- **G** (*(multi)digraph-like*) – The graph to be searched.
- **attr** (*str*) – The edge attribute used to in determining optimality.
- **default** (*float*) – The value of the edge attribute used if an edge does not have the attribute *attr*.

Returns **B** – A maximum branching.

Return type (multi)digraph-like

minimum_branching

minimum_branching (*G*, *attr*=‘weight’, *default*=1)

Returns a minimum branching from *G*.

Parameters

- **G** (*(multi)digraph-like*) – The graph to be searched.
- **attr** (*str*) – The edge attribute used to in determining optimality.
- **default** (*float*) – The value of the edge attribute used if an edge does not have the attribute *attr*.

Returns **B** – A minimum branching.

Return type (multi)digraph-like

maximum_spanning_arborescence

maximum_spanning_arborescence (*G*, *attr*=‘weight’, *default*=1)

Returns a maximum spanning arborescence from *G*.

Parameters

- **G** (*(multi)digraph-like*) – The graph to be searched.
- **attr** (*str*) – The edge attribute used to in determining optimality.

- **default** (*float*) – The value of the edge attribute used if an edge does not have the attribute *attr*.

Returns **B** – A maximum spanning arborescence.

Return type (multi)digraph-like

Raises `NetworkXException` – If the graph does not contain a maximum spanning arborescence.

minimum_spanning_arborescence

minimum_spanning_arborescence (*G*, *attr*='weight', *default*=1)

Returns a minimum spanning arborescence from *G*.

Parameters

- **G** ((*multi*)digraph-like) – The graph to be searched.
- **attr** (*str*) – The edge attribute used to in determining optimality.
- **default** (*float*) – The value of the edge attribute used if an edge does not have the attribute *attr*.

Returns **B** – A minimum spanning arborescence.

Return type (multi)digraph-like

Raises `NetworkXException` – If the graph does not contain a minimum spanning arborescence.

Edmonds

class Edmonds (*G*, *seed*=None)

Edmonds algorithm for finding optimal branchings and spanning arborescences.

__init__ (*G*, *seed*=None)

Methods

__init__ (*G*[, *seed*])

find_optimum ([*attr*, *default*, *kind*, *style*]) Returns a branching from *G*.

4.41 Triads

Functions for analyzing triads of a graph.

triadic_census (*G*) Determines the triadic census of a directed graph.

4.41.1 triadic_census

triadic_census (*G*)

Determines the triadic census of a directed graph.

The triadic census is a count of how many of the 16 possible types of triads are present in a directed graph.

Parameters **G** (*digraph*) – A NetworkX DiGraph

Returns `census` – Dictionary with triad names as keys and number of occurrences as values.

Return type `dict`

Notes

This algorithm has complexity $O(m)$ where m is the number of edges in the graph.

References

4.42 Vitality

Vitality measures.

`closeness_vitality(G[, weight])` Compute closeness vitality for nodes.

4.42.1 closeness_vitality

`closeness_vitality` (*G*, *weight=None*)

Compute closeness vitality for nodes.

Closeness vitality of a node is the change in the sum of distances between all node pairs when excluding that node.

Parameters

- ***G*** (*graph*) –
- ***weight*** (*None or string (optional)*) – The name of the edge attribute used as weight. If *None* the edge weights are ignored.

Returns `nodes` – Dictionary with nodes as keys and closeness vitality as the value.

Return type `dictionary`

Examples

```
>>> G=nx.cycle_graph(3)
>>> nx.closeness_vitality(G)
{0: 4.0, 1: 4.0, 2: 4.0}
```

See also:

`closeness centrality()`

References

FUNCTIONS

Functional interface to graph methods and assorted utilities.

5.1 Graph

<code>degree(G[, nbunch, weight])</code>	Return degree of single node or of nbunch of nodes.
<code>degree_histogram(G)</code>	Return a list of the frequency of each degree value.
<code>density(G)</code>	Return the density of a graph.
<code>info(G[, n])</code>	Print short summary of information for the graph G or the node n.
<code>create_empty_copy(G[, with_nodes])</code>	Return a copy of the graph G with all of the edges removed.
<code>is_directed(G)</code>	Return True if graph is directed.

5.1.1 degree

degree (*G*, *nbunch=None*, *weight=None*)

Return degree of single node or of nbunch of nodes. If nbunch is omitted, then return degrees of *all* nodes.

5.1.2 degree_histogram

degree_histogram (*G*)

Return a list of the frequency of each degree value.

Parameters *G* (*Networkx graph*) – A graph

Returns *hist* – A list of frequencies of degrees. The degree values are the index in the list.

Return type *list*

Notes

Note: the bins are width one, hence len(list) can be large (Order(number_of_edges))

5.1.3 density

density (*G*)

Return the density of a graph.

The density for undirected graphs is

$$d = \frac{2m}{n(n-1)},$$

and for directed graphs is

$$d = \frac{m}{n(n-1)},$$

where n is the number of nodes and m is the number of edges in G .

Notes

The density is 0 for a graph without edges and 1 for a complete graph. The density of multigraphs can be higher than 1.

Self loops are counted in the total number of edges so graphs with self loops can have density higher than 1.

5.1.4 info

info (G , $n=None$)

Print short summary of information for the graph G or the node n .

Parameters

- **G** (*Networkx graph*) – A graph
- **n** (*node (any hashable)*) – A node in the graph G

5.1.5 create_empty_copy

create_empty_copy (G , $with_nodes=True$)

Return a copy of the graph G with all of the edges removed.

Parameters

- **G** (*graph*) – A NetworkX graph
- **with_nodes** (*bool (default=True)*) – Include nodes.

Notes

Graph, node, and edge data is not propagated to the new graph.

5.1.6 is_directed

is_directed (G)

Return True if graph is directed.

5.2 Nodes

<code>nodes(G)</code>	Return a copy of the graph nodes in a list.
<code>number_of_nodes(G)</code>	Return the number of nodes in the graph.
<code>nodes_iter(G)</code>	Return an iterator over the graph nodes.
<code>all_neighbors(graph, node)</code>	Returns all of the neighbors of a node in the graph.
<code>non_neighbors(graph, node)</code>	Returns the non-neighbors of the node in the graph.
<code>common_neighbors(G, u, v)</code>	Return the common neighbors of two nodes in a graph.

5.2.1 nodes

nodes (*G*)

Return a copy of the graph nodes in a list.

5.2.2 number_of_nodes

number_of_nodes (*G*)

Return the number of nodes in the graph.

5.2.3 nodes_iter

nodes_iter (*G*)

Return an iterator over the graph nodes.

5.2.4 all_neighbors

all_neighbors (*graph, node*)

Returns all of the neighbors of a node in the graph.

If the graph is directed returns predecessors as well as successors.

Parameters

- **graph** (*NetworkX graph*) – Graph to find neighbors.
- **node** (*node*) – The node whose neighbors will be returned.

Returns **neighbors** – Iterator of neighbors

Return type iterator

5.2.5 non_neighbors

non_neighbors (*graph, node*)

Returns the non-neighbors of the node in the graph.

Parameters

- **graph** (*NetworkX graph*) – Graph to find neighbors.
- **node** (*node*) – The node whose neighbors will be returned.

Returns **non_neighbors** – Iterator of nodes in the graph that are not neighbors of the node.

Return type iterator

5.2.6 common_neighbors

common_neighbors (*G*, *u*, *v*)

Return the common neighbors of two nodes in a graph.

Parameters

- **G** (*graph*) – A NetworkX undirected graph.
- **v** (*u*,) – Nodes in the graph.

Returns **cnbors** – Iterator of common neighbors of *u* and *v* in the graph.

Return type iterator

Raises **NetworkXError** – If *u* or *v* is not a node in the graph.

Examples

```
>>> G = nx.complete_graph(5)
>>> sorted(nx.common_neighbors(G, 0, 1))
[2, 3, 4]
```

5.3 Edges

<code>edges(G[, nbunch])</code>	Return list of edges incident to nodes in <i>nbunch</i> .
<code>number_of_edges(G)</code>	Return the number of edges in the graph.
<code>edges_iter(G[, nbunch])</code>	Return iterator over edges incident to nodes in <i>nbunch</i> .
<code>non_edges(graph)</code>	Returns the non-existent edges in the graph.

5.3.1 edges

edges (*G*, *nbunch=None*)

Return list of edges incident to nodes in *nbunch*.

Return all edges if *nbunch* is unspecified or *nbunch=None*.

For digraphs, *edges=out_edges*

5.3.2 number_of_edges

number_of_edges (*G*)

Return the number of edges in the graph.

5.3.3 edges_iter

edges_iter (*G*, *nbunch=None*)

Return iterator over edges incident to nodes in *nbunch*.

Return all edges if *nbunch* is unspecified or *nbunch=None*.

For digraphs, *edges=out_edges*

5.3.4 non_edges

non_edges (*graph*)

Returns the non-existent edges in the graph.

Parameters **graph** (*NetworkX graph.*) – Graph to find non-existent edges.

Returns **non_edges** – Iterator of edges that are not in the graph.

Return type iterator

5.4 Attributes

<code>set_node_attributes(G, name, values)</code>	Set node attributes from dictionary of nodes and values
<code>get_node_attributes(G, name)</code>	Get node attributes from graph
<code>set_edge_attributes(G, name, values)</code>	Set edge attributes from dictionary of edge tuples and values.
<code>get_edge_attributes(G, name)</code>	Get edge attributes from graph

5.4.1 set_node_attributes

set_node_attributes (*G, name, values*)

Set node attributes from dictionary of nodes and values

Parameters

- **G** (*NetworkX Graph*) –
- **name** (*string*) – Attribute name
- **values** (*dict*) – Dictionary of attribute values keyed by node. If *values* is not a dictionary, then it is treated as a single attribute value that is then applied to every node in *G*.

Examples

```
>>> G = nx.path_graph(3)
>>> bb = nx.betweenness_centrality(G)
>>> nx.set_node_attributes(G, 'betweenness', bb)
>>> G.node[1]['betweenness']
1.0
```

5.4.2 get_node_attributes

get_node_attributes (*G, name*)

Get node attributes from graph

Parameters

- **G** (*NetworkX Graph*) –
- **name** (*string*) – Attribute name

Returns

Return type Dictionary of attributes keyed by node.

Examples

```
>>> G=nx.Graph()
>>> G.add_nodes_from([1,2,3],color='red')
>>> color=nx.get_node_attributes(G,'color')
>>> color[1]
'red'
```

5.4.3 set_edge_attributes

set_edge_attributes (*G, name, values*)

Set edge attributes from dictionary of edge tuples and values.

Parameters

- **G** (*NetworkX Graph*) –
- **name** (*string*) – Attribute name
- **values** (*dict*) – Dictionary of attribute values keyed by edge (tuple). For multigraphs, the keys tuples must be of the form (u, v, key). For non-multigraphs, the keys must be tuples of the form (u, v). If *values* is not a dictionary, then it is treated as a single attribute value that is then applied to every edge in *G*.

Examples

```
>>> G = nx.path_graph(3)
>>> bb = nx.edge_betweenness centrality(G, normalized=False)
>>> nx.set_edge_attributes(G, 'betweenness', bb)
>>> G[1][2]['betweenness']
2.0
```

5.4.4 get_edge_attributes

get_edge_attributes (*G, name*)

Get edge attributes from graph

Parameters

- **G** (*NetworkX Graph*) –
- **name** (*string*) – Attribute name

Returns

- *Dictionary of attributes keyed by edge. For (di)graphs, the keys are*
- **2-tuples of the form** ((u,v). *For multi(di)graphs, the keys are 3-tuples of*
- **the form** ((u, v, key).)

Examples

```
>>> G=nx.Graph()
>>> G.add_path([1,2,3],color='red')
>>> color=nx.get_edge_attributes(G,'color')
>>> color[(1,2)]
'red'
```

5.5 Freezing graph structure

<code>freeze(G)</code>	Modify graph to prevent further change by adding or removing nodes or edges.
<code>is_frozen(G)</code>	Return True if graph is frozen.

5.5.1 freeze

freeze(G)

Modify graph to prevent further change by adding or removing nodes or edges.

Node and edge data can still be modified.

G [graph] A NetworkX graph

Examples

```
>>> G=nx.Graph()
>>> G.add_path([0,1,2,3])
>>> G=nx.freeze(G)
>>> try:
...     G.add_edge(4,5)
... except nx.NetworkXError as e:
...     print(str(e))
Frozen graph can't be modified
```

Notes

To “unfreeze” a graph you must make a copy by creating a new graph object:

```
>>> graph = nx.path_graph(4)
>>> frozen_graph = nx.freeze(graph)
>>> unfrozen_graph = nx.Graph(frozen_graph)
>>> nx.is_frozen(unfrozen_graph)
False
```

See also:

`is_frozen()`

5.5.2 is_frozen

is_frozen(G)

Return True if graph is frozen.

G [graph] A NetworkX graph

See also:

freeze()

GRAPH GENERATORS

6.1 Atlas

Generators for the small graph atlas.

See “An Atlas of Graphs” by Ronald C. Read and Robin J. Wilson, Oxford University Press, 1998.

Because of its size, this module is not imported by default.

`graph_atlas_g()` Return the list [G0,G1,...,G1252] of graphs as named in the Graph Atlas.

6.1.1 graph_atlas_g

graph_atlas_g()

Return the list [G0,G1,...,G1252] of graphs as named in the Graph Atlas. G0,G1,...,G1252 are all graphs with up to 7 nodes.

The graphs are listed:

1. in increasing order of number of nodes;
2. for a fixed number of nodes, in increasing order of the number of edges;
3. for fixed numbers of nodes and edges, in increasing order of the degree sequence, for example 111223 < 112222;
4. for fixed degree sequence, in increasing number of automorphisms.

Note that indexing is set up so that for GAG=graph_atlas_g(), then G123=GAG[123] and G[0]=empty_graph(0)

6.2 Classic

Generators for some classic graphs.

The typical graph generator is called as follows:

```
>>> G=nx.complete_graph(100)
```

returning the complete graph on n nodes labeled 0,...,99 as a simple graph. Except for empty_graph, all the generators in this module return a Graph class (i.e. a simple, undirected graph).

`balanced_tree(r, h[, create_using])` Return the perfectly balanced r-tree of height h.

Cont

Table 6.2 – continued from previous page

<code>barbell_graph(m1, m2[, create_using])</code>	Return the Barbell Graph: two complete graphs connected by a path.
<code>complete_graph(n[, create_using])</code>	Return the complete graph K_n with n nodes.
<code>complete_multipartite_graph(*block_sizes)</code>	Returns the complete multipartite graph with the specified block sizes.
<code>circular_ladder_graph(n[, create_using])</code>	Return the circular ladder graph CL_n of length n .
<code>cycle_graph(n[, create_using])</code>	Return the cycle graph C_n over n nodes.
<code>dorogovtsev_goltsev_mendes_graph(n[, ...])</code>	Return the hierarchically constructed Dorogovtsev-Goltsev-Mendes graph.
<code>empty_graph(n[, create_using])</code>	Return the empty graph with n nodes and zero edges.
<code>grid_2d_graph(m, n[, periodic, create_using])</code>	Return the 2d grid graph of $m \times n$ nodes, each connected to its nearest neighbors.
<code>grid_graph(dim[, periodic])</code>	Return the n -dimensional grid graph.
<code>hypercube_graph(n)</code>	Return the n -dimensional hypercube.
<code>ladder_graph(n[, create_using])</code>	Return the Ladder graph of length n .
<code>lollipop_graph(m, n[, create_using])</code>	Return the Lollipop Graph; K_m connected to P_n .
<code>null_graph([create_using])</code>	Return the Null graph with no nodes or edges.
<code>path_graph(n[, create_using])</code>	Return the Path graph P_n of n nodes linearly connected by $n-1$ edges.
<code>star_graph(n[, create_using])</code>	Return the Star graph with $n+1$ nodes: one center node, connected to n outer nodes.
<code>trivial_graph([create_using])</code>	Return the Trivial graph with one node (with integer label 0) and no edges.
<code>wheel_graph(n[, create_using])</code>	Return the wheel graph: a single hub node connected to each node of the $(n-1)$ -cycle.

6.2.1 balanced_tree

balanced_tree (*r, h, create_using=None*)

Return the perfectly balanced r -tree of height h .

Parameters

- **r** (*int*) – Branching factor of the tree
- **h** (*int*) – Height of the tree
- **create_using** (*NetworkX graph type, optional*) – Use specified type to construct graph (default = `networkx.Graph`)

Returns **G** – A tree with n nodes

Return type `networkx.Graph`

Notes

This is the rooted tree where all leaves are at distance h from the root. The root has degree r and all other internal nodes have degree $r+1$.

Node labels are the integers 0 (the root) up to `number_of_nodes - 1`.

Also referred to as a complete r -ary tree.

6.2.2 barbell_graph

barbell_graph (*m1, m2, create_using=None*)

Return the Barbell Graph: two complete graphs connected by a path.

For $m1 > 1$ and $m2 \geq 0$.

Two identical complete graphs K_{m1} form the left and right bells, and are connected by a path P_{m2} .

The $2*m_1+m_2$ nodes are numbered $0, \dots, m_1-1$ for the left barbell, m_1, \dots, m_1+m_2-1 for the path, and $m_1+m_2, \dots, 2*m_1+m_2-1$ for the right barbell.

The 3 subgraphs are joined via the edges (m_1-1, m_1) and (m_1+m_2-1, m_1+m_2) . If $m_2=0$, this is merely two complete graphs joined together.

This graph is an extremal example in David Aldous and Jim Fill's etext on Random Walks on Graphs.

6.2.3 complete_graph

complete_graph (*n*, *create_using=None*)

Return the complete graph K_n with n nodes.

Node labels are the integers 0 to $n-1$.

6.2.4 complete_multipartite_graph

complete_multipartite_graph (**block_sizes*)

Returns the complete multipartite graph with the specified block sizes.

Parameters **block_sizes** (*tuple of integers*) – The number of vertices in each block of the multipartite graph. The length of this tuple is the number of blocks.

Returns

G –

Returns the complete multipartite graph with the specified block sizes.

For each node, the node attribute 'block' is an integer indicating which block contains the node.

Return type NetworkX Graph

Examples

Creating a complete tripartite graph, with blocks of one, two, and three vertices, respectively.

```
>>> import networkx as nx
>>> G = nx.complete_multipartite_graph(1, 2, 3)
>>> [G.node[u]['block'] for u in G]
[0, 1, 1, 2, 2, 2]
>>> G.edges(0)
[(0, 1), (0, 2), (0, 3), (0, 4), (0, 5)]
>>> G.edges(2)
[(2, 0), (2, 3), (2, 4), (2, 5)]
>>> G.edges(4)
[(4, 0), (4, 1), (4, 2)]
```

Notes

This function generalizes several other graph generator functions.

- If no block sizes are given, this returns the null graph.
- If a single block size n is given, this returns the empty graph on n nodes.

- If two block sizes m and n are given, this returns the complete bipartite graph on $m + n$ nodes.
- If block sizes 1 and n are given, this returns the star graph on $n + 1$ nodes.

See also:

`complete_bipartite_graph()`

6.2.5 circular_ladder_graph

circular_ladder_graph (n , *create_using=None*)

Return the circular ladder graph CL_n of length n .

CL_n consists of two concentric n -cycles in which each of the n pairs of concentric nodes are joined by an edge.

Node labels are the integers 0 to $n-1$

6.2.6 cycle_graph

cycle_graph (n , *create_using=None*)

Return the cycle graph C_n over n nodes.

C_n is the n -path with two end-nodes connected.

Node labels are the integers 0 to $n-1$. If *create_using* is a `DiGraph`, the direction is in increasing order.

6.2.7 dorogovtsev_goltsev_mendes_graph

dorogovtsev_goltsev_mendes_graph (n , *create_using=None*)

Return the hierarchically constructed Dorogovtsev-Goltsev-Mendes graph.

n is the generation. See: [arXiv:/cond-mat/0112143](https://arxiv.org/abs/cond-mat/0112143) by Dorogovtsev, Goltsev and Mendes.

6.2.8 empty_graph

empty_graph ($n=0$, *create_using=None*)

Return the empty graph with n nodes and zero edges.

Node labels are the integers 0 to $n-1$

For example: `>>> G=nx.empty_graph(10) >>> G.number_of_nodes() 10 >>> G.number_of_edges() 0`

The variable *create_using* should point to a “graph”-like object that will be cleaned (nodes and edges will be removed) and refitted as an empty “graph” with n nodes with integer labels. This capability is useful for specifying the class-nature of the resulting empty “graph” (i.e. `Graph`, `DiGraph`, `MyWeirdGraphClass`, etc.).

The variable *create_using* has two main uses: Firstly, the variable *create_using* can be used to create an empty digraph, network, etc. For example,

```
>>> n=10
>>> G=nx.empty_graph(n, create_using=nx.DiGraph())
```

will create an empty digraph on n nodes.

Secondly, one can pass an existing graph (digraph, pseudograph, etc.) via *create_using*. For example, if G is an existing graph (resp. digraph, pseudograph, etc.), then `empty_graph(n, create_using=G)` will empty G (i.e. delete all nodes and edges using `G.clear()` in base) and then add n nodes and zero edges, and return the modified graph (resp. digraph, pseudograph, etc.).

See also `create_empty_copy(G)`.

6.2.9 grid_2d_graph

grid_2d_graph (*m, n, periodic=False, create_using=None*)

Return the 2d grid graph of $m \times n$ nodes, each connected to its nearest neighbors. Optional argument `periodic=True` will connect boundary nodes via periodic boundary conditions.

6.2.10 grid_graph

grid_graph (*dim, periodic=False*)

Return the n -dimensional grid graph.

The dimension is the length of the list 'dim' and the size in each dimension is the value of the list element.

E.g. `G=grid_graph(dim=[2,3])` produces a 2×3 grid graph.

If `periodic=True` then join grid edges with periodic boundary conditions.

6.2.11 hypercube_graph

hypercube_graph (*n*)

Return the n -dimensional hypercube.

Node labels are the integers 0 to $2^n - 1$.

6.2.12 ladder_graph

ladder_graph (*n, create_using=None*)

Return the Ladder graph of length n .

This is two rows of n nodes, with each pair connected by a single edge.

Node labels are the integers 0 to $2n - 1$.

6.2.13 lollipop_graph

lollipop_graph (*m, n, create_using=None*)

Return the Lollipop Graph; K_m connected to P_n .

This is the Barbell Graph without the right barbell.

For $m > 1$ and $n \geq 0$, the complete graph K_m is connected to the path P_n . The resulting $m+n$ nodes are labelled $0, \dots, m-1$ for the complete graph and $m, \dots, m+n-1$ for the path. The 2 subgraphs are joined via the edge $(m-1, m)$. If $n=0$, this is merely a complete graph.

Node labels are the integers 0 to `number_of_nodes - 1`.

(This graph is an extremal example in David Aldous and Jim Fill's etext on Random Walks on Graphs.)

6.2.14 null_graph

null_graph (*create_using=None*)

Return the Null graph with no nodes or edges.

See empty_graph for the use of create_using.

6.2.15 path_graph

path_graph (*n, create_using=None*)

Return the Path graph P_n of n nodes linearly connected by $n-1$ edges.

Node labels are the integers 0 to $n - 1$. If create_using is a DiGraph then the edges are directed in increasing order.

6.2.16 star_graph

star_graph (*n, create_using=None*)

Return the Star graph with $n+1$ nodes: one center node, connected to n outer nodes.

Node labels are the integers 0 to n .

6.2.17 trivial_graph

trivial_graph (*create_using=None*)

Return the Trivial graph with one node (with integer label 0) and no edges.

6.2.18 wheel_graph

wheel_graph (*n, create_using=None*)

Return the wheel graph: a single hub node connected to each node of the $(n-1)$ -node cycle graph.

Node labels are the integers 0 to $n - 1$.

6.3 Expanders

Provides explicit constructions of expander graphs.

<code>margulis_gabber_galil_graph</code> (n [, create_using])	Return the Margulis-Gabber-Galil undirected MultiGraph on n^2 nodes.
<code>chordal_cycle_graph</code> (p [, create_using])	Return the chordal cycle graph on p nodes.

6.3.1 margulis_gabber_galil_graph

margulis_gabber_galil_graph (*n, create_using=None*)

Return the Margulis-Gabber-Galil undirected MultiGraph on n^2 nodes.

The undirected MultiGraph is regular with degree 8. Nodes are integer pairs. The second-largest eigenvalue of the adjacency matrix of the graph is at most $5\sqrt{2}$, regardless of n .

Parameters

- **n** (*int*) – Determines the number of nodes in the graph: n^2 .
- **create_using** (*graph-like*) – A graph-like object that receives the constructed edges. If `None`, then a *MultiGraph* instance is used.

Returns **G** – The constructed undirected multigraph.

Return type `graph`

Raises `NetworkXError` – If the graph is directed or not a multigraph.

6.3.2 chordal_cycle_graph

chordal_cycle_graph (*p*, *create_using=None*)

Return the chordal cycle graph on *p* nodes.

The returned graph is a cycle graph on *p* nodes with chords joining each vertex *x* to its inverse modulo *p*. This graph is a (mildly explicit) 3-regular expander¹.

p must be a prime number.

Parameters

- **p** (*a prime number*) – The number of vertices in the graph. This also indicates where the chordal edges in the cycle will be created.
- **create_using** (*graph-like*) – A graph-like object that receives the constructed edges. If `None`, then a *MultiGraph* instance is used.

Returns **G** – The constructed undirected multigraph.

Return type `graph`

Raises `NetworkXError` –

If the graph provided in `create_using` is directed or not a multigraph.

References

6.4 Small

Various small and named graphs, together with some compact generators.

<code>make_small_graph(graph_description[, ...])</code>	Return the small graph described by <code>graph_description</code> .
<code>LCF_graph(n, shift_list, repeats[, create_using])</code>	Return the cubic graph specified in LCF notation.
<code>bull_graph([create_using])</code>	Return the Bull graph.
<code>chvatal_graph([create_using])</code>	Return the Chvátal graph.
<code>cubical_graph([create_using])</code>	Return the 3-regular Platonic Cubical graph.
<code>desargues_graph([create_using])</code>	Return the Desargues graph.
<code>diamond_graph([create_using])</code>	Return the Diamond graph.
<code>dodecahedral_graph([create_using])</code>	Return the Platonic Dodecahedral graph.
<code>frucht_graph([create_using])</code>	Return the Frucht Graph.
<code>heawood_graph([create_using])</code>	Return the Heawood graph, a (3,6) cage.
<code>house_graph([create_using])</code>	Return the House graph (square with triangle on top).

Continued on next page

¹ Theorem 4.4.2 in A. Lubotzky. “Discrete groups, expanding graphs and invariant measures”, volume 125 of Progress in Mathematics. Birkhäuser Verlag, Basel, 1994.

Table 6.4 – continued from previous page

<code>house_x_graph([create_using])</code>	Return the House graph with a cross inside the house square.
<code>icosahedral_graph([create_using])</code>	Return the Platonic Icosahedral graph.
<code>krackhardt_kite_graph([create_using])</code>	Return the Krackhardt Kite Social Network.
<code>moebius_kantor_graph([create_using])</code>	Return the Moebius-Kantor graph.
<code>octahedral_graph([create_using])</code>	Return the Platonic Octahedral graph.
<code>pappus_graph()</code>	Return the Pappus graph.
<code>petersen_graph([create_using])</code>	Return the Petersen graph.
<code>sedgewick_maze_graph([create_using])</code>	Return a small maze with a cycle.
<code>tetrahedral_graph([create_using])</code>	Return the 3-regular Platonic Tetrahedral graph.
<code>truncated_cube_graph([create_using])</code>	Return the skeleton of the truncated cube.
<code>truncated_tetrahedron_graph([create_using])</code>	Return the skeleton of the truncated Platonic tetrahedron.
<code>tutte_graph([create_using])</code>	Return the Tutte graph.

6.4.1 make_small_graph

make_small_graph (*graph_description*, *create_using=None*)

Return the small graph described by *graph_description*.

graph_description is a list of the form [*ltype*,*name*,*n*,*xlist*]

Here *ltype* is one of “adjacencylist” or “edgelist”, *name* is the name of the graph and *n* the number of nodes. This constructs a graph of *n* nodes with integer labels 0,...,*n*-1.

If *ltype*=“adjacencylist” then *xlist* is an adjacency list with exactly *n* entries, in with the *j*’th entry (which can be empty) specifies the nodes connected to vertex *j*. e.g. the “square” graph *C_4* can be obtained by

```
>>> G=nx.make_small_graph(["adjacencylist", "C_4", 4, [[2,4], [1,3], [2,4], [1,3]]])
```

or, since we do not need to add edges twice,

```
>>> G=nx.make_small_graph(["adjacencylist", "C_4", 4, [[2,4], [3], [4], []]])
```

If *ltype*=“edgelist” then *xlist* is an edge list written as [[*v*₁,*w*₂],[*v*₂,*w*₂],...,[*v*_k,*w*_k]], where *v*_j and *w*_j integers in the range 1,...,*n* e.g. the “square” graph *C_4* can be obtained by

```
>>> G=nx.make_small_graph(["edgelist", "C_4", 4, [[1,2], [3,4], [2,3], [4,1]]])
```

Use the *create_using* argument to choose the graph class/type.

6.4.2 LCF_graph

LCF_graph (*n*, *shift_list*, *repeats*, *create_using=None*)

Return the cubic graph specified in LCF notation.

LCF notation (LCF=Lederberg-Coxeter-Fruchte) is a compressed notation used in the generation of various cubic Hamiltonian graphs of high symmetry. See, for example, `dodecahedral_graph`, `desargues_graph`, `heawood_graph` and `pappus_graph` below.

n (number of nodes) The starting graph is the *n*-cycle with nodes 0,...,*n*-1. (The null graph is returned if *n* < 0.)

shift_list = [*s*₁,*s*₂,...,*s*_k], a list of integer shifts mod *n*,

repeats integer specifying the number of times that shifts in *shift_list* are successively applied to each *v*_{current} in the *n*-cycle to generate an edge between *v*_{current} and *v*_{current}+shift mod *n*.

For v_1 cycling through the n -cycle a total of k *repeats with shift cycling through shiftlist repeats times connect v_1 with $v_1 + \text{shift} \bmod n$

The utility graph $K_{\{3,3\}}$

```
>>> G=nx.LCF_graph(6, [3, -3], 3)
```

The Heawood graph

```
>>> G=nx.LCF_graph(14, [5, -5], 7)
```

See <http://mathworld.wolfram.com/LCFNotation.html> for a description and references.

6.4.3 bull_graph

bull_graph (*create_using=None*)
Return the Bull graph.

6.4.4 chvatal_graph

chvatal_graph (*create_using=None*)
Return the Chvátal graph.

6.4.5 cubical_graph

cubical_graph (*create_using=None*)
Return the 3-regular Platonic Cubical graph.

6.4.6 desargues_graph

desargues_graph (*create_using=None*)
Return the Desargues graph.

6.4.7 diamond_graph

diamond_graph (*create_using=None*)
Return the Diamond graph.

6.4.8 dodecahedral_graph

dodecahedral_graph (*create_using=None*)
Return the Platonic Dodecahedral graph.

6.4.9 Frucht_graph

Frucht_graph (*create_using=None*)
Return the Frucht Graph.

The Frucht Graph is the smallest cubical graph whose automorphism group consists only of the identity element.

6.4.10 heawood_graph

heawood_graph (*create_using=None*)
Return the Heawood graph, a (3,6) cage.

6.4.11 house_graph

house_graph (*create_using=None*)
Return the House graph (square with triangle on top).

6.4.12 house_x_graph

house_x_graph (*create_using=None*)
Return the House graph with a cross inside the house square.

6.4.13 icosahedral_graph

icosahedral_graph (*create_using=None*)
Return the Platonic Icosahedral graph.

6.4.14 krackhardt_kite_graph

krackhardt_kite_graph (*create_using=None*)
Return the Krackhardt Kite Social Network.

A 10 actor social network introduced by David Krackhardt to illustrate: degree, betweenness, centrality, closeness, etc. The traditional labeling is: Andre=1, Beverley=2, Carol=3, Diane=4, Ed=5, Fernando=6, Garth=7, Heather=8, Ike=9, Jane=10.

6.4.15 moebius_kantor_graph

moebius_kantor_graph (*create_using=None*)
Return the Moebius-Kantor graph.

6.4.16 octahedral_graph

octahedral_graph (*create_using=None*)
Return the Platonic Octahedral graph.

6.4.17 pappus_graph

pappus_graph ()
Return the Pappus graph.

6.4.18 petersen_graph

petersen_graph (*create_using=None*)
Return the Petersen graph.

6.4.19 `sedgewick_maze_graph`

`sedgewick_maze_graph` (*create_using=None*)

Return a small maze with a cycle.

This is the maze used in Sedgewick, 3rd Edition, Part 5, Graph Algorithms, Chapter 18, e.g. Figure 18.2 and following. Nodes are numbered 0,...,7

6.4.20 `tetrahedral_graph`

`tetrahedral_graph` (*create_using=None*)

Return the 3-regular Platonic Tetrahedral graph.

6.4.21 `truncated_cube_graph`

`truncated_cube_graph` (*create_using=None*)

Return the skeleton of the truncated cube.

6.4.22 `truncated_tetrahedron_graph`

`truncated_tetrahedron_graph` (*create_using=None*)

Return the skeleton of the truncated Platonic tetrahedron.

6.4.23 `tutte_graph`

`tutte_graph` (*create_using=None*)

Return the Tutte graph.

6.5 Random Graphs

Generators for random graphs.

<code>fast_gnp_random_graph(n, p[, seed, directed])</code>	Returns a $G_{n,p}$ random graph, also known as an Erdős-Rényi graph or a
<code>gnp_random_graph(n, p[, seed, directed])</code>	Returns a $G_{n,p}$ random graph, also known as an Erdős-Rényi graph or a
<code>dense_gnm_random_graph(n, m[, seed])</code>	Returns a $G_{n,m}$ random graph.
<code>gnm_random_graph(n, m[, seed, directed])</code>	Returns a $G_{n,m}$ random graph.
<code>erdos_renyi_graph(n, p[, seed, directed])</code>	Returns a $G_{n,p}$ random graph, also known as an Erdős-Rényi graph or a
<code>binomial_graph(n, p[, seed, directed])</code>	Returns a $G_{n,p}$ random graph, also known as an Erdős-Rényi graph or a
<code>newman_watts_strogatz_graph(n, k, p[, seed])</code>	Return a Newman-Watts-Strogatz small-world graph.
<code>watts_strogatz_graph(n, k, p[, seed])</code>	Return a Watts-Strogatz small-world graph.
<code>connected_watts_strogatz_graph(n, k, p[, ...])</code>	Returns a connected Watts-Strogatz small-world graph.
<code>random_regular_graph(d, n[, seed])</code>	Returns a random d -regular graph on n nodes.
<code>barabasi_albert_graph(n, m[, seed])</code>	Returns a random graph according to the Barabási-Albert preferential a
<code>powerlaw_cluster_graph(n, m, p[, seed])</code>	Holme and Kim algorithm for growing graphs with powerlaw degree di
<code>duplication_divergence_graph(n, p[, seed])</code>	Returns an undirected graph using the duplication-divergence model.
<code>random_lobster(n, p1, p2[, seed])</code>	Returns a random lobster graph.
<code>random_shell_graph(constructor[, seed])</code>	Returns a random shell graph for the constructor given.
<code>random_powerlaw_tree(n[, gamma, seed, tries])</code>	Returns a tree with a power law degree distribution.

Table 6.5 – continued from previous page

<code>random_powerlaw_tree_sequence(n[, gamma, ...])</code>	Returns a degree sequence for a tree with a power law distribution.
---	---

6.5.1 fast_gnp_random_graph

fast_gnp_random_graph (*n*, *p*, *seed=None*, *directed=False*)

Returns a $G_{n,p}$ random graph, also known as an Erdős-Rényi graph or a binomial graph.

Parameters

- **n** (*int*) – The number of nodes.
- **p** (*float*) – Probability for edge creation.
- **seed** (*int, optional*) – Seed for random number generator (default=None).
- **directed** (*bool, optional (default=False)*) – If `True`, this function returns a directed graph.

Notes

The $G_{n,p}$ graph algorithm chooses each of the $[n(n-1)]/2$ (undirected) or $n(n-1)$ (directed) possible edges with probability p .

This algorithm runs in $O(n+m)$ time, where m is the expected number of edges, which equals $pn(n-1)/2$. This should be faster than `gnp_random_graph()` when p is small and the expected number of edges is small (that is, the graph is sparse).

See also:

`gnp_random_graph()`

References

6.5.2 gnp_random_graph

gnp_random_graph (*n*, *p*, *seed=None*, *directed=False*)

Returns a $G_{n,p}$ random graph, also known as an Erdős-Rényi graph or a binomial graph.

The $G_{n,p}$ model chooses each of the possible edges with probability p .

The functions `binomial_graph()` and `erdos_renyi_graph()` are aliases of this function.

Parameters

- **n** (*int*) – The number of nodes.
- **p** (*float*) – Probability for edge creation.
- **seed** (*int, optional*) – Seed for random number generator (default=None).
- **directed** (*bool, optional (default=False)*) – If `True`, this function returns a directed graph.

See also:

`fast_gnp_random_graph()`

Notes

This algorithm runs in $O(n^2)$ time. For sparse graphs (that is, for small values of p), `fast_gnp_random_graph()` is a faster algorithm.

References

6.5.3 dense_gnm_random_graph

dense_gnm_random_graph ($n, m, seed=None$)

Returns a $G_{n,m}$ random graph.

In the $G_{n,m}$ model, a graph is chosen uniformly at random from the set of all graphs with n nodes and m edges.

This algorithm should be faster than `gnm_random_graph()` for dense graphs.

Parameters

- **n** (*int*) – The number of nodes.
- **m** (*int*) – The number of edges.
- **seed** (*int, optional*) – Seed for random number generator (default=None).

See also:

`gnm_random_graph()`

Notes

Algorithm by Keith M. Briggs Mar 31, 2006. Inspired by Knuth's Algorithm S (Selection sampling technique), in section 3.4.2 of ².

References

6.5.4 gnm_random_graph

gnm_random_graph ($n, m, seed=None, directed=False$)

Returns a $G_{n,m}$ random graph.

In the $G_{n,m}$ model, a graph is chosen uniformly at random from the set of all graphs with n nodes and m edges.

This algorithm should be faster than `dense_gnm_random_graph()` for sparse graphs.

Parameters

- **n** (*int*) – The number of nodes.
- **m** (*int*) – The number of edges.
- **seed** (*int, optional*) – Seed for random number generator (default=None).
- **directed** (*bool, optional (default=False)*) – If True return a directed graph

See also:

`dense_gnm_random_graph()`

² Donald E. Knuth, The Art of Computer Programming, Volume 2/Seminumerical algorithms, Third Edition, Addison-Wesley, 1997.

6.5.5 erdos_renyi_graph

erdos_renyi_graph (*n*, *p*, *seed*=None, *directed*=False)

Returns a $G_{n,p}$ random graph, also known as an Erdős-Rényi graph or a binomial graph.

The $G_{n,p}$ model chooses each of the possible edges with probability *p*.

The functions `binomial_graph()` and `erdos_renyi_graph()` are aliases of this function.

Parameters

- **n** (*int*) – The number of nodes.
- **p** (*float*) – Probability for edge creation.
- **seed** (*int*, *optional*) – Seed for random number generator (default=None).
- **directed** (*bool*, *optional* (default=False)) – If True, this function returns a directed graph.

See also:

`fast_gnp_random_graph()`

Notes

This algorithm runs in $O(n^2)$ time. For sparse graphs (that is, for small values of *p*), `fast_gnp_random_graph()` is a faster algorithm.

References

6.5.6 binomial_graph

binomial_graph (*n*, *p*, *seed*=None, *directed*=False)

Returns a $G_{n,p}$ random graph, also known as an Erdős-Rényi graph or a binomial graph.

The $G_{n,p}$ model chooses each of the possible edges with probability *p*.

The functions `binomial_graph()` and `erdos_renyi_graph()` are aliases of this function.

Parameters

- **n** (*int*) – The number of nodes.
- **p** (*float*) – Probability for edge creation.
- **seed** (*int*, *optional*) – Seed for random number generator (default=None).
- **directed** (*bool*, *optional* (default=False)) – If True, this function returns a directed graph.

See also:

`fast_gnp_random_graph()`

Notes

This algorithm runs in $O(n^2)$ time. For sparse graphs (that is, for small values of *p*), `fast_gnp_random_graph()` is a faster algorithm.

References

6.5.7 `newman_watts_strogatz_graph`

`newman_watts_strogatz_graph` (*n*, *k*, *p*, *seed=None*)

Return a Newman–Watts–Strogatz small-world graph.

Parameters

- *n* (*int*) – The number of nodes.
- *k* (*int*) – Each node is joined with its *k* nearest neighbors in a ring topology.
- *p* (*float*) – The probability of adding a new edge for each edge.
- *seed* (*int*, *optional*) – The seed for the random number generator (the default is `None`).

Notes

First create a ring over *n* nodes. Then each node in the ring is connected with its *k* nearest neighbors (or *k* – 1 neighbors if *k* is odd). Then shortcuts are created by adding new edges as follows: for each edge (*u*, *v*) in the underlying “*n*-ring with *k* nearest neighbors” with probability *p* add a new edge (*u*, *w*) with randomly-chosen existing node *w*. In contrast with `watts_strogatz_graph()`, no edges are removed.

See also:

`watts_strogatz_graph()`

References

6.5.8 `watts_strogatz_graph`

`watts_strogatz_graph` (*n*, *k*, *p*, *seed=None*)

Return a Watts–Strogatz small-world graph.

Parameters

- *n* (*int*) – The number of nodes
- *k* (*int*) – Each node is joined with its *k* nearest neighbors in a ring topology.
- *p* (*float*) – The probability of rewiring each edge
- *seed* (*int*, *optional*) – Seed for random number generator (default=`None`)

See also:

`newman_watts_strogatz_graph()`, `connected_watts_strogatz_graph()`

Notes

First create a ring over *n* nodes. Then each node in the ring is joined to its *k* nearest neighbors (or *k* – 1 neighbors if *k* is odd). Then shortcuts are created by replacing some edges as follows: for each edge (*u*, *v*) in the underlying “*n*-ring with *k* nearest neighbors” with probability *p* replace it with a new edge (*u*, *w*) with uniformly random choice of existing node *w*.

In contrast with `newman_watts_strogatz_graph()`, the random rewiring does not increase the number of edges. The rewired graph is not guaranteed to be connected as in `connected_watts_strogatz_graph()`.

References

6.5.9 connected_watts_strogatz_graph

connected_watts_strogatz_graph (*n*, *k*, *p*, *tries*=100, *seed*=None)

Returns a connected Watts–Strogatz small-world graph.

Attempts to generate a connected graph by repeated generation of Watts–Strogatz small-world graphs. An exception is raised if the maximum number of tries is exceeded.

Parameters

- **n** (*int*) – The number of nodes
- **k** (*int*) – Each node is joined with its *k* nearest neighbors in a ring topology.
- **p** (*float*) – The probability of rewiring each edge
- **tries** (*int*) – Number of attempts to generate a connected graph.
- **seed** (*int*, *optional*) – The seed for random number generator.

See also:

`newman_watts_strogatz_graph()`, `watts_strogatz_graph()`

6.5.10 random_regular_graph

random_regular_graph (*d*, *n*, *seed*=None)

Returns a random *d*-regular graph on *n* nodes.

The resulting graph has no self-loops or parallel edges.

Parameters

- **d** (*int*) – The degree of each node.
- **n** (*integer*) – The number of nodes. The value of $n * d$ must be even.
- **seed** (*hashable object*) – The seed for random number generator.

Notes

The nodes are numbered from 0 to $n - 1$.

Kim and Vu’s paper ³ shows that this algorithm samples in an asymptotically uniform way from the space of random graphs when $d = O(n^{1/3-\epsilon})$.

Raises `NetworkXError` – If $n * d$ is odd or *d* is greater than or equal to *n*.

³ Jeong Han Kim and Van H. Vu, Generating random regular graphs, Proceedings of the thirty-fifth ACM symposium on Theory of computing, San Diego, CA, USA, pp 213–222, 2003. <http://portal.acm.org/citation.cfm?id=780542.780576>

References

6.5.11 `barabasi_albert_graph`

`barabasi_albert_graph` (*n*, *m*, *seed*=None)

Returns a random graph according to the Barabási–Albert preferential attachment model.

A graph of *n* nodes is grown by attaching new nodes each with *m* edges that are preferentially attached to existing nodes with high degree.

Parameters

- *n* (*int*) – Number of nodes
- *m* (*int*) – Number of edges to attach from a new node to existing nodes
- *seed* (*int*, *optional*) – Seed for random number generator (default=None).

Returns *G*

Return type *Graph*

Raises `NetworkXError` – If *m* does not satisfy $1 \leq m < n$.

References

6.5.12 `powerlaw_cluster_graph`

`powerlaw_cluster_graph` (*n*, *m*, *p*, *seed*=None)

Holme and Kim algorithm for growing graphs with powerlaw degree distribution and approximate average clustering.

Parameters

- *n* (*int*) – the number of nodes
- *m* (*int*) – the number of random edges to add for each new node
- *p* (*float*,) – Probability of adding a triangle after adding a random edge
- *seed* (*int*, *optional*) – Seed for random number generator (default=None).

Notes

The average clustering has a hard time getting above a certain cutoff that depends on *m*. This cutoff is often quite low. The transitivity (fraction of triangles to possible triangles) seems to decrease with network size.

It is essentially the Barabási–Albert (BA) growth model with an extra step that each random edge is followed by a chance of making an edge to one of its neighbors too (and thus a triangle).

This algorithm improves on BA in the sense that it enables a higher average clustering to be attained if desired.

It seems possible to have a disconnected graph with this algorithm since the initial *m* nodes may not be all linked to a new node on the first iteration like the BA model.

Raises `NetworkXError` – If *m* does not satisfy $1 \leq m \leq n$ or *p* does not satisfy $0 \leq p \leq 1$.

References

6.5.13 duplication_divergence_graph

duplication_divergence_graph (*n*, *p*, *seed=None*)

Returns an undirected graph using the duplication-divergence model.

A graph of *n* nodes is created by duplicating the initial nodes and retaining edges incident to the original nodes with a retention probability *p*.

Parameters

- **n** (*int*) – The desired number of nodes in the graph.
- **p** (*float*) – The probability for retaining the edge of the replicated node.
- **seed** (*int*, *optional*) – A seed for the random number generator of `random` (default=None).

Returns

G

Return type *Graph*

Raises `NetworkXError` – If *p* is not a valid probability. If *n* is less than 2.

References

6.5.14 random_lobster

random_lobster (*n*, *p1*, *p2*, *seed=None*)

Returns a random lobster graph.

A lobster is a tree that reduces to a caterpillar when pruning all leaf nodes. A caterpillar is a tree that reduces to a path graph when pruning all leaf nodes; setting *p2* to zero produces a caterpillar.

Parameters

- **n** (*int*) – The expected number of nodes in the backbone
- **p1** (*float*) – Probability of adding an edge to the backbone
- **p2** (*float*) – Probability of adding an edge one level beyond backbone
- **seed** (*int*, *optional*) – Seed for random number generator (default=None).

6.5.15 random_shell_graph

random_shell_graph (*constructor*, *seed=None*)

Returns a random shell graph for the constructor given.

Parameters

- **constructor** (*list of three-tuples*) – Represents the parameters for a shell, starting at the center shell. Each element of the list must be of the form (*n*, *m*, *d*), where *n* is the number of nodes in the shell, *m* is the number of edges in the shell, and *d* is the ratio of inter-shell (next) edges to intra-shell edges. If *d* is zero, there will be no intra-shell edges, and if *d* is one there will be all possible intra-shell edges.
- **seed** (*int*, *optional*) – Seed for random number generator (default=None).

Examples

```
>>> constructor = [(10, 20, 0.8), (20, 40, 0.8)]
>>> G = nx.random_shell_graph(constructor)
```

6.5.16 random_powerlaw_tree

random_powerlaw_tree (*n*, *gamma*=3, *seed*=None, *tries*=100)

Returns a tree with a power law degree distribution.

Parameters

- **n** (*int*) – The number of nodes.
- **gamma** (*float*) – Exponent of the power law.
- **seed** (*int*, *optional*) – Seed for random number generator (default=None).
- **tries** (*int*) – Number of attempts to adjust the sequence to make it a tree.

Raises NetworkXError – If no valid sequence is found within the maximum number of attempts.

Notes

A trial power law degree sequence is chosen and then elements are swapped with new elements from a powerlaw distribution until the sequence makes a tree (by checking, for example, that the number of edges is one smaller than the number of nodes).

6.5.17 random_powerlaw_tree_sequence

random_powerlaw_tree_sequence (*n*, *gamma*=3, *seed*=None, *tries*=100)

Returns a degree sequence for a tree with a power law distribution.

Parameters

- **n** (*int*,) – The number of nodes.
- **gamma** (*float*) – Exponent of the power law.
- **seed** (*int*, *optional*) – Seed for random number generator (default=None).
- **tries** (*int*) – Number of attempts to adjust the sequence to make it a tree.

Raises NetworkXError – If no valid sequence is found within the maximum number of attempts.

Notes

A trial power law degree sequence is chosen and then elements are swapped with new elements from a power law distribution until the sequence makes a tree (by checking, for example, that the number of edges is one smaller than the number of nodes).

6.6 Degree Sequence

Generate graphs with a given degree sequence or expected degree sequence.

<code>configuration_model(deg_sequence[, ...])</code>	Return a random graph with the given degree sequence.
<code>directed_configuration_model(...[, ...])</code>	Return a directed_random graph with the given degree sequences.
<code>expected_degree_graph(w[, seed, selfloops])</code>	Return a random graph with given expected degrees.
<code>havel_hakimi_graph(deg_sequence[, create_using])</code>	Return a simple graph with given degree sequence constructed using
<code>directed_havel_hakimi_graph(in_deg_sequence, ...)</code>	Return a directed graph with the given degree sequences.
<code>degree_sequence_tree(deg_sequence[, ...])</code>	Make a tree for the given degree sequence.
<code>random_degree_sequence_graph(sequence[, ...])</code>	Return a simple random graph with the given degree sequence.

6.6.1 configuration_model

configuration_model (*deg_sequence*, *create_using=None*, *seed=None*)

Return a random graph with the given degree sequence.

The configuration model generates a random pseudograph (graph with parallel edges and self loops) by randomly assigning edges to match the given degree sequence.

Parameters

- **deg_sequence** (*list of integers*) – Each list entry corresponds to the degree of a node.
- **create_using** (*graph, optional (default MultiGraph)*) – Return graph of this type. The instance will be cleared.
- **seed** (*hashable object, optional*) – Seed for random number generator.

Returns **G** – A graph with the specified degree sequence. Nodes are labeled starting at 0 with an index corresponding to the position in *deg_sequence*.

Return type *MultiGraph*

Raises *NetworkXError* – If the degree sequence does not have an even sum.

See also:

`is_valid_degree_sequence()`

Notes

As described by Newman ⁴.

A non-graphical degree sequence (not realizable by some simple graph) is allowed since this function returns graphs with self loops and parallel edges. An exception is raised if the degree sequence does not have an even sum.

This configuration model construction process can lead to duplicate edges and loops. You can remove the self-loops and parallel edges (see below) which will likely result in a graph that doesn't have the exact degree sequence specified.

The density of self-loops and parallel edges tends to decrease as the number of nodes increases. However, typically the number of self-loops will approach a Poisson distribution with a nonzero mean, and similarly for the number of parallel edges. Consider a node with *k* stubs. The probability of being joined to another stub of the same node is basically $(k-1)/N$ where *k* is the degree and *N* is the number of nodes. So the probability of a self-loop scales like c/N for some constant *c*. As *N* grows, this means we expect *c* self-loops. Similarly for parallel edges.

⁴ M.E.J. Newman, "The structure and function of complex networks", SIAM REVIEW 45-2, pp 167-256, 2003.

References

Examples

```
>>> from networkx.utils import powerlaw_sequence
>>> z=nx.utils.create_degree_sequence(100,powerlaw_sequence)
>>> G=nx.configuration_model(z)
```

To remove parallel edges:

```
>>> G=nx.Graph(G)
```

To remove self loops:

```
>>> G.remove_edges_from(G.selfloop_edges())
```

6.6.2 directed_configuration_model

directed_configuration_model(*in_degree_sequence*, *out_degree_sequence*, *create_using=None*, *seed=None*)

Return a directed_random graph with the given degree sequences.

The configuration model generates a random directed pseudograph (graph with parallel edges and self loops) by randomly assigning edges to match the given degree sequences.

Parameters

- **in_degree_sequence** (*list of integers*) – Each list entry corresponds to the in-degree of a node.
- **out_degree_sequence** (*list of integers*) – Each list entry corresponds to the out-degree of a node.
- **create_using** (*graph, optional (default MultiDiGraph)*) – Return graph of this type. The instance will be cleared.
- **seed** (*hashable object, optional*) – Seed for random number generator.

Returns **G** – A graph with the specified degree sequences. Nodes are labeled starting at 0 with an index corresponding to the position in deg_sequence.

Return type *MultiDiGraph*

Raises *NetworkXError* – If the degree sequences do not have the same sum.

See also:

`configuration_model()`

Notes

Algorithm as described by Newman ⁵.

A non-graphical degree sequence (not realizable by some simple graph) is allowed since this function returns graphs with self loops and parallel edges. An exception is raised if the degree sequences does not have the same sum.

⁵ Newman, M. E. J. and Strogatz, S. H. and Watts, D. J. Random graphs with arbitrary degree distributions and their applications Phys. Rev. E, 64, 026118 (2001)

This configuration model construction process can lead to duplicate edges and loops. You can remove the self-loops and parallel edges (see below) which will likely result in a graph that doesn't have the exact degree sequence specified. This "finite-size effect" decreases as the size of the graph increases.

References

Examples

```
>>> D=nx.DiGraph([(0,1),(1,2),(2,3)]) # directed path graph
>>> din=list(D.in_degree().values())
>>> dout=list(D.out_degree().values())
>>> din.append(1)
>>> dout[0]=2
>>> D=nx.directed_configuration_model(din,dout)
```

To remove parallel edges:

```
>>> D=nx.DiGraph(D)
```

To remove self loops:

```
>>> D.remove_edges_from(D.selfloop_edges())
```

6.6.3 expected_degree_graph

expected_degree_graph (*w*, *seed=None*, *selfloops=True*)

Return a random graph with given expected degrees.

Given a sequence of expected degrees $W = (w_0, w_1, \dots, w_{n-1})$ of length n this algorithm assigns an edge between node u and node v with probability

$$p_{uv} = \frac{w_u w_v}{\sum_k w_k}.$$

Parameters

- **w** (*list*) – The list of expected degrees.
- **selfloops** (*bool (default=True)*) – Set to False to remove the possibility of self-loop edges.
- **seed** (*hashable object, optional*) – The seed for the random number generator.

Returns

Return type *Graph*

Examples

```
>>> z=[10 for i in range(100)]
>>> G=nx.expected_degree_graph(z)
```

Notes

The nodes have integer labels corresponding to index of expected degrees input sequence.

The complexity of this algorithm is $\mathcal{O}(n + m)$ where n is the number of nodes and m is the expected number of edges.

The model in ⁶ includes the possibility of self-loop edges. Set `selfloops=False` to produce a graph without self loops.

For finite graphs this model doesn't produce exactly the given expected degree sequence. Instead the expected degrees are as follows.

For the case without self loops (`selfloops=False`),

$$E[\deg(u)] = \sum_{v \neq u} p_{uv} = w_u \left(1 - \frac{w_u}{\sum_k w_k} \right).$$

NetworkX uses the standard convention that a self-loop edge counts 2 in the degree of a node, so with self loops (`selfloops=True`),

$$E[\deg(u)] = \sum_{v \neq u} p_{uv} + 2p_{uu} = w_u \left(1 + \frac{w_u}{\sum_k w_k} \right).$$

References

6.6.4 havel_hakimi_graph

havel_hakimi_graph (*deg_sequence*, *create_using=None*)

Return a simple graph with given degree sequence constructed using the Havel-Hakimi algorithm.

Parameters

- **deg_sequence** (*list of integers*) – Each integer corresponds to the degree of a node (need not be sorted).
- **create_using** (*graph, optional (default Graph)*) – Return graph of this type. The instance will be cleared. Directed graphs are not allowed.

Raises `NetworkXException` – For a non-graphical degree sequence (i.e. one not realizable by some simple graph).

Notes

The Havel-Hakimi algorithm constructs a simple graph by successively connecting the node of highest degree to other nodes of highest degree, resorting remaining nodes by degree, and repeating the process. The resulting graph has a high degree-associativity. Nodes are labeled 1,..., `len(deg_sequence)`, corresponding to their position in `deg_sequence`.

The basic algorithm is from Hakimi ⁷ and was generalized by Kleitman and Wang ⁸.

⁶ Fan Chung and L. Lu, Connected components in random graphs with given expected degree sequences, Ann. Combinatorics, 6, pp. 125-145, 2002.

⁷ Hakimi S., On Realizability of a Set of Integers as Degrees of the Vertices of a Linear Graph. I, Journal of SIAM, 10(3), pp. 496-506 (1962)

⁸ Kleitman D.J. and Wang D.L. Algorithms for Constructing Graphs and Digraphs with Given Valences and Factors Discrete Mathematics, 6(1), pp. 79-88 (1973)

References

6.6.5 directed_havel_hakimi_graph

directed_havel_hakimi_graph (*in_deg_sequence, out_deg_sequence, create_using=None*)

Return a directed graph with the given degree sequences.

Parameters

- **in_deg_sequence** (*list of integers*) – Each list entry corresponds to the in-degree of a node.
- **out_deg_sequence** (*list of integers*) – Each list entry corresponds to the out-degree of a node.
- **create_using** (*graph, optional (default DiGraph)*) – Return graph of this type. The instance will be cleared.

Returns **G** – A graph with the specified degree sequences. Nodes are labeled starting at 0 with an index corresponding to the position in deg_sequence

Return type *DiGraph*

Raises *NetworkXError* – If the degree sequences are not digraphical.

See also:

configuration_model()

Notes

Algorithm as described by Kleitman and Wang ⁹.

References

6.6.6 degree_sequence_tree

degree_sequence_tree (*deg_sequence, create_using=None*)

Make a tree for the given degree sequence.

A tree has #nodes-#edges=1 so the degree sequence must have $\text{len}(\text{deg_sequence}) - \text{sum}(\text{deg_sequence})/2 = 1$

6.6.7 random_degree_sequence_graph

random_degree_sequence_graph (*sequence, seed=None, tries=10*)

Return a simple random graph with the given degree sequence.

If the maximum degree d_m in the sequence is $O(m^{1/4})$ then the algorithm produces almost uniform random graphs in $O(md_m)$ time where m is the number of edges.

Parameters

- **sequence** (*list of integers*) – Sequence of degrees
- **seed** (*hashable object, optional*) – Seed for random number generator

⁹ D.J. Kleitman and D.L. Wang Algorithms for Constructing Graphs and Digraphs with Given Valences and Factors Discrete Mathematics, 6(1), pp. 79-88 (1973)

- **tries** (*int, optional*) – Maximum number of tries to create a graph

Returns **G** – A graph with the specified degree sequence. Nodes are labeled starting at 0 with an index corresponding to the position in the sequence.

Return type *Graph*

Raises

- `NetworkXUnfeasible` – If the degree sequence is not graphical.
- `NetworkXError` – If a graph is not produced in specified number of tries

See also:

`is_valid_degree_sequence()`, `configuration_model()`

Notes

The generator algorithm¹⁰ is not guaranteed to produce a graph.

References

Examples

```
>>> sequence = [1, 2, 2, 3]
>>> G = nx.random_degree_sequence_graph(sequence)
>>> sorted(G.degree().values())
[1, 2, 2, 3]
```

6.7 Random Clustered

Generate graphs with given degree and triangle sequence.

`random_clustered_graph(joint_degree_sequence)` Generate a random graph with the given joint independent edge degree and triangle degree sequence.

6.7.1 random_clustered_graph

random_clustered_graph (*joint_degree_sequence, create_using=None, seed=None*)

Generate a random graph with the given joint independent edge degree and triangle degree sequence.

This uses a configuration model-like approach to generate a random graph (with parallel edges and self-loops) by randomly assigning edges to match the given joint degree sequence.

The joint degree sequence is a list of pairs of integers of the form $[(d_{1,i}, d_{1,t}), \dots, (d_{n,i}, d_{n,t})]$. According to this list, vertex u is a member of $d_{u,t}$ triangles and has $d_{u,i}$ other edges. The number $d_{u,t}$ is the *triangle degree* of u and the number $d_{u,i}$ is the *independent edge degree*.

Parameters

¹⁰ Moshen Bayati, Jeong Han Kim, and Amin Saberi, A sequential algorithm for generating random graphs. *Algorithmica*, Volume 58, Number 4, 860-910, DOI: 10.1007/s00453-009-9340-1

- **joint_degree_sequence** (*list of integer pairs*) – Each list entry corresponds to the independent edge degree and triangle degree of a node.
- **create_using** (*graph, optional (default MultiGraph)*) – Return graph of this type. The instance will be cleared.
- **seed** (*hashable object, optional*) – The seed for the random number generator.

Returns **G** – A graph with the specified degree sequence. Nodes are labeled starting at 0 with an index corresponding to the position in `deg_sequence`.

Return type *MultiGraph*

Raises `NetworkXError` – If the independent edge degree sequence sum is not even or the triangle degree sequence sum is not divisible by 3.

Notes

As described by Miller ¹¹ (see also Newman ¹² for an equivalent description).

A non-graphical degree sequence (not realizable by some simple graph) is allowed since this function returns graphs with self loops and parallel edges. An exception is raised if the independent degree sequence does not have an even sum or the triangle degree sequence sum is not divisible by 3.

This configuration model-like construction process can lead to duplicate edges and loops. You can remove the self-loops and parallel edges (see below) which will likely result in a graph that doesn't have the exact degree sequence specified. This "finite-size effect" decreases as the size of the graph increases.

References

Examples

```
>>> deg = [(1, 0), (1, 0), (1, 0), (2, 0), (1, 0), (2, 1), (0, 1), (0, 1)]
>>> G = nx.random_clustered_graph(deg)
```

To remove parallel edges:

```
>>> G = nx.Graph(G)
```

To remove self loops:

```
>>> G.remove_edges_from(G.selfloop_edges())
```

6.8 Directed

Generators for some directed graphs, including growing network (GN) graphs and scale-free graphs.

<code>gn_graph(n[, kernel, create_using, seed])</code>	Return the growing network (GN) digraph with <code>n</code> nodes.
<code>gnr_graph(n, p[, create_using, seed])</code>	Return the growing network with redirection (GNR) digraph with <code>n</code> nodes and
<code>gnc_graph(n[, create_using, seed])</code>	Return the growing network with copying (GNC) digraph with <code>n</code> nodes.
<code>scale_free_graph(n[, alpha, beta, gamma, ...])</code>	Returns a scale-free directed graph.

¹¹ Joel C. Miller. "Percolation and epidemics in random clustered networks". In: Physical review. E, Statistical, nonlinear, and soft matter physics 80 (2 Part 1 August 2009).

¹² M. E. J. Newman. "Random Graphs with Clustering". In: Physical Review Letters 103 (5 July 2009)

6.8.1 gn_graph

gn_graph (*n*, *kernel*=None, *create_using*=None, *seed*=None)

Return the growing network (GN) digraph with *n* nodes.

The GN graph is built by adding nodes one at a time with a link to one previously added node. The target node for the link is chosen with probability based on degree. The default attachment kernel is a linear function of the degree of a node.

The graph is always a (directed) tree.

Parameters

- **n** (*int*) – The number of nodes for the generated graph.
- **kernel** (*function*) – The attachment kernel.
- **create_using** (*graph*, *optional (default DiGraph)*) – Return graph of this type. The instance will be cleared.
- **seed** (*hashable object, optional*) – The seed for the random number generator.

Examples

To create the undirected GN graph, use the `to_undirected()` method:

```
>>> D = nx.gn_graph(10) # the GN graph
>>> G = D.to_undirected() # the undirected version
```

To specify an attachment kernel, use the `kernel` keyword argument:

```
>>> D = nx.gn_graph(10, kernel=lambda x: x ** 1.5) # A_k = k^1.5
```

References

6.8.2 gnr_graph

gnr_graph (*n*, *p*, *create_using*=None, *seed*=None)

Return the growing network with redirection (GNR) digraph with *n* nodes and redirection probability *p*.

The GNR graph is built by adding nodes one at a time with a link to one previously added node. The previous target node is chosen uniformly at random. With probability *p* the link is instead “redirected” to the successor node of the target.

The graph is always a (directed) tree.

Parameters

- **n** (*int*) – The number of nodes for the generated graph.
- **p** (*float*) – The redirection probability.
- **create_using** (*graph*, *optional (default DiGraph)*) – Return graph of this type. The instance will be cleared.
- **seed** (*hashable object, optional*) – The seed for the random number generator.

Examples

To create the undirected GNR graph, use the `to_undirected()` method:

```
>>> D = nx.gnr_graph(10, 0.5) # the GNR graph
>>> G = D.to_undirected()    # the undirected version
```

References

6.8.3 gnc_graph

gnc_graph (*n*, *create_using=None*, *seed=None*)

Return the growing network with copying (GNC) digraph with *n* nodes.

The GNC graph is built by adding nodes one at a time with a link to one previously added node (chosen uniformly at random) and to all of that node's successors.

Parameters

- **n** (*int*) – The number of nodes for the generated graph.
- **create_using** (*graph*, *optional* (default *DiGraph*)) – Return graph of this type. The instance will be cleared.
- **seed** (*hashable object*, *optional*) – The seed for the random number generator.

References

6.8.4 scale_free_graph

scale_free_graph (*n*, *alpha=0.41*, *beta=0.54*, *gamma=0.05*, *delta_in=0.2*, *delta_out=0*, *create_using=None*, *seed=None*)

Returns a scale-free directed graph.

Parameters

- **n** (*integer*) – Number of nodes in graph
- **alpha** (*float*) – Probability for adding a new node connected to an existing node chosen randomly according to the in-degree distribution.
- **beta** (*float*) – Probability for adding an edge between two existing nodes. One existing node is chosen randomly according to the in-degree distribution and the other chosen randomly according to the out-degree distribution.
- **gamma** (*float*) – Probability for adding a new node connected to an existing node chosen randomly according to the out-degree distribution.
- **delta_in** (*float*) – Bias for choosing nodes from in-degree distribution.
- **delta_out** (*float*) – Bias for choosing nodes from out-degree distribution.
- **create_using** (*graph*, *optional* (default *MultiDiGraph*)) – Use this graph instance to start the process (default=3-cycle).
- **seed** (*integer*, *optional*) – Seed for random number generator

Examples

Create a scale-free graph on one hundred nodes:

```
>>> G = nx.scale_free_graph(100)
```

Notes

The sum of `alpha`, `beta`, and `gamma` must be 1.

References

6.9 Geometric

Generators for geometric graphs.

<code>random_geometric_graph(n, radius[, dim, pos])</code>	Returns a random geometric graph in the unit cube.
<code>geographical_threshold_graph(n, theta[, ...])</code>	Returns a geographical threshold graph.
<code>waxman_graph(n[, alpha, beta, L, domain])</code>	Return a Waxman random graph.
<code>navigable_small_world_graph(n[, p, q, r, ...])</code>	Return a navigable small-world graph.

6.9.1 random_geometric_graph

random_geometric_graph (*n*, *radius*, *dim*=2, *pos*=None)

Returns a random geometric graph in the unit cube.

The random geometric graph model places *n* nodes uniformly at random in the unit cube. Two nodes are joined by an edge if the Euclidean distance between the nodes is at most *radius*.

Parameters

- **n** (*int*) – Number of nodes
- **radius** (*float*) – Distance threshold value
- **dim** (*int*, *optional*) – Dimension of graph
- **pos** (*dict*, *optional*) – A dictionary keyed by node with node positions as values.

Returns

Return type *Graph*

Examples

Create a random geometric graph on twenty nodes where nodes are joined by an edge if their distance is at most 0.1:

```
>>> G = nx.random_geometric_graph(20, 0.1)
```

Notes

This algorithm currently only supports Euclidean distance.

This uses an $O(n^2)$ algorithm to build the graph. A faster algorithm is possible using k-d trees.

The `pos` keyword argument can be used to specify node positions so you can create an arbitrary distribution and domain for positions.

For example, to use a 2D Gaussian distribution of node positions with mean (0, 0) and standard deviation 2:

```
>>> import random
>>> n = 20
>>> p = {i: (random.gauss(0, 2), random.gauss(0, 2)) for i in range(n)}
>>> G = nx.random_geometric_graph(n, 0.2, pos=p)
```

References

6.9.2 geographical_threshold_graph

geographical_threshold_graph (*n*, *theta*, *alpha*=2, *dim*=2, *pos*=None, *weight*=None)

Returns a geographical threshold graph.

The geographical threshold graph model places *n* nodes uniformly at random in a rectangular domain. Each node *u* is assigned a weight w_u . Two nodes *u* and *v* are joined by an edge if

$$w_u + w_v \geq \theta r^\alpha$$

where *r* is the Euclidean distance between *u* and *v*, and θ , α are parameters.

Parameters

- **n** (*int*) – Number of nodes
- **theta** (*float*) – Threshold value
- **alpha** (*float*, *optional*) – Exponent of distance function
- **dim** (*int*, *optional*) – Dimension of graph
- **pos** (*dict*) – Node positions as a dictionary of tuples keyed by node.
- **weight** (*dict*) – Node weights as a dictionary of numbers keyed by node.

Returns

Return type *Graph*

Examples

```
>>> G = nx.geographical_threshold_graph(20, 50)
```

Notes

If weights are not specified they are assigned to nodes by drawing randomly from the exponential distribution with rate parameter $\lambda = 1$. To specify weights from a different distribution, use the `weight` keyword argument:

```
>>> import random
>>> n = 20
>>> w = {i: random.expovariate(5.0) for i in range(n)}
>>> G = nx.geographical_threshold_graph(20, 50, weight=w)
```

If node positions are not specified they are randomly assigned from the uniform distribution.

References

6.9.3 waxman_graph

waxman_graph (*n*, *alpha*=0.4, *beta*=0.1, *L*=None, *domain*=(0, 0, 1, 1))

Return a Waxman random graph.

The Waxman random graph model places *n* nodes uniformly at random in a rectangular domain. Each pair of nodes at Euclidean distance *d* is joined by an edge with probability

$$p = \alpha \exp(-d/\beta L).$$

This function implements both Waxman models, using the *L* keyword argument.

- Waxman-1: if *L* is not specified, it is set to be the maximum distance between any pair of nodes.
- Waxman-2: if *L* is specified, the distance between a pair of nodes is chosen uniformly at random from the interval $[0, L]$.

Parameters

- **n** (*int*) – Number of nodes
- **alpha** (*float*) – Model parameter
- **beta** (*float*) – Model parameter
- **L** (*float, optional*) – Maximum distance between nodes. If not specified, the actual distance is calculated.
- **domain** (*four-tuple of numbers, optional*) – Domain size, given as a tuple of the form $(x_{min}, y_{min}, x_{max}, y_{max})$.

Returns

G
Return type *Graph*

References

6.9.4 navigable_small_world_graph

navigable_small_world_graph (*n*, *p*=1, *q*=1, *r*=2, *dim*=2, *seed*=None)

Return a navigable small-world graph.

A navigable small-world graph is a directed grid with additional long-range connections that are chosen randomly.

[...] we begin with a set of nodes [...] that are identified with the set of lattice points in an $n \times n$ square, $\{(i, j) : i \in \{1, 2, \dots, n\}, j \in \{1, 2, \dots, n\}\}$, and we define the *lattice distance* between two nodes (i, j) and (k, l) to be the number of “lattice steps” separating them: $d((i, j), (k, l)) = |k - i| + |l - j|$. For a universal constant $p \geq 1$, the node *u* has a directed edge to every other node within

lattice distance p — these are its *local contacts*. For universal constants $q \geq 0$ and $r \geq 0$ we also construct directed edges from u to q other nodes (the *long-range contacts*) using independent random trials; the i 'th directed edge from u has endpoint v with probability proportional to $[d(u, v)]^{-r}$.

13

Parameters

- **n** (*int*) – The number of nodes.
- **p** (*int*) – The diameter of short range connections. Each node is joined with every other node within this lattice distance.
- **q** (*int*) – The number of long-range connections for each node.
- **r** (*float*) – Exponent for decaying probability of connections. The probability of connecting to a node at lattice distance d is $1/d^r$.
- **dim** (*int*) – Dimension of grid
- **seed** (*int, optional*) – Seed for random number generator (default=None).

References

6.10 Line Graph

Functions for generating line graphs.

`line_graph(G[, create_using])` Returns the line graph of the graph or digraph G .

6.10.1 line_graph

line_graph (G , *create_using=None*)

Returns the line graph of the graph or digraph G .

The line graph of a graph G has a node for each edge in G and an edge joining those nodes if the two edges in G share a common node. For directed graphs, nodes are adjacent exactly when the edges they represent form a directed path of length two.

The nodes of the line graph are 2-tuples of nodes in the original graph (or 3-tuples for multigraphs, with the key of the edge as the third element).

For information about self-loops and more discussion, see the **Notes** section below.

Parameters G (*graph*) – A NetworkX Graph, DiGraph, MultiGraph, or MultiDiGraph.

Returns L – The line graph of G .

Return type graph

Examples

¹³ J. Kleinberg. The small-world phenomenon: An algorithmic perspective. Proc. 32nd ACM Symposium on Theory of Computing, 2000.

```
>>> import networkx as nx
>>> G = nx.star_graph(3)
>>> L = nx.line_graph(G)
>>> print(sorted(map(sorted, L.edges())) # makes a 3-clique, K3
[[ (0, 1), (0, 2)], [(0, 1), (0, 3)], [(0, 2), (0, 3)]]
```

Notes

Graph, node, and edge data are not propagated to the new graph. For undirected graphs, the nodes in G must be sortable, otherwise the constructed line graph may not be correct.

Self-loops in undirected graphs

For an undirected graph G without multiple edges, each edge can be written as a set $\{u, v\}$. Its line graph L has the edges of G as its nodes. If x and y are two nodes in L , then $\{x, y\}$ is an edge in L if and only if the intersection of x and y is nonempty. Thus, the set of all edges is determined by the set of all pairwise intersections of edges in G .

Trivially, every edge in G would have a nonzero intersection with itself, and so every node in L should have a self-loop. This is not so interesting, and the original context of line graphs was with simple graphs, which had no self-loops or multiple edges. The line graph was also meant to be a simple graph and thus, self-loops in L are not part of the standard definition of a line graph. In a pairwise intersection matrix, this is analogous to excluding the diagonal entries from the line graph definition.

Self-loops and multiple edges in G add nodes to L in a natural way, and do not require any fundamental changes to the definition. It might be argued that the self-loops we excluded before should now be included. However, the self-loops are still “trivial” in some sense and thus, are usually excluded.

Self-loops in directed graphs

For a directed graph G without multiple edges, each edge can be written as a tuple (u, v) . Its line graph L has the edges of G as its nodes. If x and y are two nodes in L , then (x, y) is an edge in L if and only if the tail of x matches the head of y , for example, if $x = (a, b)$ and $y = (b, c)$ for some vertices a, b , and c in G .

Due to the directed nature of the edges, it is no longer the case that every edge in G should have a self-loop in L . Now, the only time self-loops arise is if a node in G itself has a self-loop. So such self-loops are no longer “trivial” but instead, represent essential features of the topology of G . For this reason, the historical development of line digraphs is such that self-loops are included. When the graph G has multiple edges, once again only superficial changes are required to the definition.

References

- Harary, Frank, and Norman, Robert Z., “Some properties of line digraphs”, Rend. Circ. Mat. Palermo, II. Ser. 9 (1960), 161–168.
- Hemminger, R. L.; Beineke, L. W. (1978), “Line graphs and line digraphs”, in Beineke, L. W.; Wilson, R. J., Selected Topics in Graph Theory, Academic Press Inc., pp. 271–305.

6.11 Ego Graph

Ego graph.

`ego_graph(G, n[, radius, center, ...])` Returns induced subgraph of neighbors centered at node n within a given radius.

6.11.1 ego_graph

ego_graph (*G*, *n*, *radius*=1, *center*=True, *undirected*=False, *distance*=None)

Returns induced subgraph of neighbors centered at node *n* within a given radius.

Parameters

- **G** (*graph*) – A NetworkX Graph or DiGraph
- **n** (*node*) – A single node
- **radius** (*number*, *optional*) – Include all neighbors of distance \leq radius from *n*.
- **center** (*bool*, *optional*) – If False, do not include center node in graph
- **undirected** (*bool*, *optional*) – If True use both in- and out-neighbors of directed graphs.
- **distance** (*key*, *optional*) – Use specified edge data key as distance. For example, setting *distance*='weight' will use the edge weight to measure the distance from the node *n*.

Notes

For directed graphs *D* this produces the “out” neighborhood or successors. If you want the neighborhood of predecessors first reverse the graph with *D*.reverse(). If you want both directions use the keyword argument *undirected*=True.

Node, edge, and graph attributes are copied to the returned subgraph.

6.12 Stochastic

Functions for generating stochastic graphs from a given weighted directed graph.

stochastic_graph(*G*[, *copy*, *weight*]) Returns a right-stochastic representation of the directed graph *G*.

6.12.1 stochastic_graph

stochastic_graph (*G*, *copy*=True, *weight*='weight')

Returns a right-stochastic representation of the directed graph *G*.

A right-stochastic graph is a weighted digraph in which for each node, the sum of the weights of all the out-edges of that node is 1. If the graph is already weighted (for example, via a 'weight' edge attribute), the reweighting takes that into account.

G [directed graph] A NetworkX DiGraph

copy [boolean, optional] If this is True, then this function returns a new instance of `networkx.Digraph`. Otherwise, the original graph is modified in-place (and also returned, for convenience).

weight [edge attribute key (optional, default='weight')] Edge attribute key used for reading the existing weight and setting the new weight. If no attribute with this key is found for an edge, then the edge weight is assumed to be 1. If an edge has a weight, it must be a positive number.

6.13 Intersection

Generators for random intersection graphs.

<code>uniform_random_intersection_graph(n, m, p[, ...])</code>	Return a uniform random intersection graph.
<code>k_random_intersection_graph(n, m, k)</code>	Return a intersection graph with randomly chosen attribute sets for each node.
<code>general_random_intersection_graph(n, m, p)</code>	Return a random intersection graph with independent probabilities for connections between node and attribute sets.

6.13.1 uniform_random_intersection_graph

uniform_random_intersection_graph(*n*, *m*, *p*, *seed=None*)

Return a uniform random intersection graph.

Parameters

- **n** (*int*) – The number of nodes in the first bipartite set (nodes)
- **m** (*int*) – The number of nodes in the second bipartite set (attributes)
- **p** (*float*) – Probability of connecting nodes between bipartite sets
- **seed** (*int, optional*) – Seed for random number generator (default=None).

See also:

`gnp_random_graph()`

References

6.13.2 k_random_intersection_graph

k_random_intersection_graph(*n*, *m*, *k*)

Return a intersection graph with randomly chosen attribute sets for each node that are of equal size (*k*).

Parameters

- **n** (*int*) – The number of nodes in the first bipartite set (nodes)
- **m** (*int*) – The number of nodes in the second bipartite set (attributes)
- **k** (*float*) – Size of attribute set to assign to each node.
- **seed** (*int, optional*) – Seed for random number generator (default=None).

See also:

`gnp_random_graph()`, `uniform_random_intersection_graph()`

References

6.13.3 general_random_intersection_graph

general_random_intersection_graph(*n*, *m*, *p*)

Return a random intersection graph with independent probabilities for connections between node and attribute sets.

Parameters

- **n** (*int*) – The number of nodes in the first bipartite set (nodes)
- **m** (*int*) – The number of nodes in the second bipartite set (attributes)
- **p** (*list of floats of length m*) – Probabilities for connecting nodes to each attribute
- **seed** (*int, optional*) – Seed for random number generator (default=None).

See also:

`gnp_random_graph()`, `uniform_random_intersection_graph()`

References

6.14 Social Networks

Famous social networks.

<code>karate_club_graph()</code>	Return Zachary's Karate Club graph.
<code>davis_southern_women_graph()</code>	Return Davis Southern women social network.
<code>florentine_families_graph()</code>	Return Florentine families graph.

6.14.1 karate_club_graph

karate_club_graph()

Return Zachary's Karate Club graph.

Each node in the returned graph has a node attribute 'club' that indicates the name of the club to which the member represented by that node belongs, either 'Mr. Hi' or 'Officer'.

Examples

To get the name of the club to which a node belongs:

```
>>> import networkx as nx
>>> G = nx.karate_club_graph()
>>> G.node[5]['club']
'Mr. Hi'
>>> G.node[9]['club']
'Officer'
```

References

6.14.2 davis_southern_women_graph

davis_southern_women_graph()

Return Davis Southern women social network.

This is a bipartite graph.

References

6.14.3 florentine_families_graph

florentine_families_graph()

Return Florentine families graph.

References

6.15 Community

Generators for classes of graphs used in studying social networks.

<code>caveman_graph(l, k)</code>	Returns a caveman graph of <code>l</code> cliques of size <code>k</code> .
<code>connected_caveman_graph(l, k)</code>	Returns a connected caveman graph of <code>l</code> cliques of size <code>k</code> .
<code>relaxed_caveman_graph(l, k, p[, seed])</code>	Return a relaxed caveman graph.
<code>random_partition_graph(sizes, p_in, p_out[, ...])</code>	Return the random partition graph with a partition of sizes.
<code>planted_partition_graph(l, k, p_in, p_out[, ...])</code>	Return the planted <code>l</code> -partition graph.
<code>gaussian_random_partition_graph(n, s, v, ...)</code>	Generate a Gaussian random partition graph.

6.15.1 caveman_graph

caveman_graph(l, k)Returns a caveman graph of `l` cliques of size `k`.**Parameters**

- **l** (*int*) – Number of cliques
- **k** (*int*) – Size of cliques

Returns **G** – caveman graph**Return type** NetworkX Graph**Notes**

This returns an undirected graph, it can be converted to a directed graph using `nx.to_directed()`, or a multigraph using `nx.MultiGraph(nx.caveman_graph(l, k))`. Only the undirected version is described in ¹⁴ and it is unclear which of the directed generalizations is most useful.

Examples

```
>>> G = nx.caveman_graph(3, 3)
```

See also:

`connected_caveman_graph()`

¹⁴ Watts, D. J. 'Networks, Dynamics, and the Small-World Phenomenon.' Amer. J. Soc. 105, 493-527, 1999.

References

6.15.2 connected_caveman_graph

connected_caveman_graph (*l*, *k*)

Returns a connected caveman graph of *l* cliques of size *k*.

The connected caveman graph is formed by creating *n* cliques of size *k*, then a single edge in each clique is rewired to a node in an adjacent clique.

Parameters

- **l** (*int*) – number of cliques
- **k** (*int*) – size of cliques

Returns **G** – connected caveman graph

Return type NetworkX Graph

Notes

This returns an undirected graph, it can be converted to a directed graph using `nx.to_directed()`, or a multigraph using `nx.MultiGraph(nx.caveman_graph(l, k))`. Only the undirected version is described in ¹⁵ and it is unclear which of the directed generalizations is most useful.

Examples

```
>>> G = nx.connected_caveman_graph(3, 3)
```

References

6.15.3 relaxed_caveman_graph

relaxed_caveman_graph (*l*, *k*, *p*, *seed=None*)

Return a relaxed caveman graph.

A relaxed caveman graph starts with *l* cliques of size *k*. Edges are then randomly rewired with probability *p* to link different cliques.

Parameters

- **l** (*int*) – Number of groups
- **k** (*int*) – Size of cliques
- **p** (*float*) – Probability of rewiring each edge.
- **seed** (*int, optional*) – Seed for random number generator(default=None)

Returns **G** – Relaxed Caveman Graph

Return type NetworkX Graph

Raises `NetworkXError` – If *p* is not in [0,1]

¹⁵ Watts, D. J. ‘Networks, Dynamics, and the Small-World Phenomenon.’ Amer. J. Soc. 105, 493-527, 1999.

Examples

```
>>> G = nx.relaxed_caveman_graph(2, 3, 0.1, seed=42)
```

References

6.15.4 random_partition_graph

random_partition_graph (*sizes, p_in, p_out, seed=None, directed=False*)

Return the random partition graph with a partition of sizes.

A partition graph is a graph of communities with sizes defined by *s* in *sizes*. Nodes in the same group are connected with probability *p_in* and nodes of different groups are connected with probability *p_out*.

Parameters

- **sizes** (*list of ints*) – Sizes of groups
- **p_in** (*float*) – probability of edges with in groups
- **p_out** (*float*) – probability of edges between groups
- **directed** (*boolean optional, default=False*) – Whether to create a directed graph
- **seed** (*int optional, default None*) – A seed for the random number generator

Returns **G** – random partition graph of size sum(*gs*)

Return type NetworkX Graph or DiGraph

Raises **NetworkXError** – If *p_in* or *p_out* is not in [0,1]

Examples

```
>>> G = nx.random_partition_graph([10,10,10], .25, .01)
>>> len(G)
30
>>> partition = G.graph['partition']
>>> len(partition)
3
```

Notes

This is a generalization of the planted-l-partition described in ¹⁶. It allows for the creation of groups of any size. The partition is store as a graph attribute ‘partition’.

References

6.15.5 planted_partition_graph

planted_partition_graph (*l, k, p_in, p_out, seed=None, directed=False*)

Return the planted l-partition graph.

¹⁶ Santo Fortunato ‘Community Detection in Graphs’ Physical Reports Volume 486, Issue 3-5 p. 75-174. <http://arxiv.org/abs/0906.0612>

This model partitions a graph with $n=l*k$ vertices in l groups with k vertices each. Vertices of the same group are linked with a probability p_{in} , and vertices of different groups are linked with probability p_{out} .

Parameters

- **`l`** (*int*) – Number of groups
- **`k`** (*int*) – Number of vertices in each group
- **`p_in`** (*float*) – probability of connecting vertices within a group
- **`p_out`** (*float*) – probability of connected vertices between groups
- **`seed`** (*int, optional*) – Seed for random number generator(default=None)
- **`directed`** (*bool, optional (default=False)*) – If True return a directed graph

Returns **`G`** – planted l -partition graph

Return type NetworkX Graph or DiGraph

Raises NetworkXError – If p_{in}, p_{out} are not in $[0,1]$ or

Examples

```
>>> G = nx.planted_partition_graph(4, 3, 0.5, 0.1, seed=42)
```

See also:

`random_partition_model()`

References

6.15.6 gaussian_random_partition_graph

gaussian_random_partition_graph (*n, s, v, p_in, p_out, directed=False, seed=None*)

Generate a Gaussian random partition graph.

A Gaussian random partition graph is created by creating k partitions each with a size drawn from a normal distribution with mean s and variance s/v . Nodes are connected within clusters with probability p_{in} and between clusters with probability $p_{out}[1]$

Parameters

- **`n`** (*int*) – Number of nodes in the graph
- **`s`** (*float*) – Mean cluster size
- **`v`** (*float*) – Shape parameter. The variance of cluster size distribution is s/v .
- **`p_in`** (*float*) – Probability of intra cluster connection.
- **`p_out`** (*float*) – Probability of inter cluster connection.
- **`directed`** (*boolean, optional default=False*) – Whether to create a directed graph or not
- **`seed`** (*int*) – Seed value for random number generator

Returns **`G`** – gaussian random partition graph

Return type NetworkX Graph or DiGraph

Raises NetworkXError – If s is $> n$ If p_{in} or p_{out} is not in $[0,1]$

Notes

Note the number of partitions is dependent on s, v and n , and that the last partition may be considerably smaller, as it is sized to simply fill out the nodes [1]

See also:

`random_partition_graph()`

Examples

```
>>> G = nx.gaussian_random_partition_graph(100,10,10,.25,.1)
>>> len(G)
100
```

References

6.16 Non Isomorphic Trees

Implementation of the Wright, Richmond, Odlyzko and McKay (WROM) algorithm for the enumeration of all non-isomorphic free trees of a given order. Rooted trees are represented by level sequences, i.e., lists in which the i -th element specifies the distance of vertex i to the root.

<code>nonisomorphic_trees(order[, create])</code>	Returns a list of nonisomorphic trees
<code>number_of_nonisomorphic_trees(order)</code>	Returns the number of nonisomorphic trees

6.16.1 nonisomorphic_trees

nonisomorphic_trees (*order*, *create*='graph')

Returns a list of nonisomorphic trees

Parameters

- **order** (*int*) – order of the desired tree(s)
- **create** (*graph or matrix (default="Graph")*) – If graph is selected a list of trees will be returned, if matrix is selected a list of adjacency matrix will be returned

Returns

- **G** (*List of NetworkX Graphs*)
- **M** (*List of Adjacency matrices*)

References

6.16.2 number_of_nonisomorphic_trees

number_of_nonisomorphic_trees (*order*)

Returns the number of nonisomorphic trees

Parameters **order** (*int*) – order of the desired tree(s)

Returns length

Return type Number of nonisomorphic graphs for the given order

References

LINEAR ALGEBRA

7.1 Graph Matrix

Adjacency matrix and incidence matrix of graphs.

<code>adjacency_matrix(G[, nodelist, weight])</code>	Return adjacency matrix of G.
<code>incidence_matrix(G[, nodelist, edgelist, ...])</code>	Return incidence matrix of G.

7.1.1 adjacency_matrix

adjacency_matrix (*G*, *nodelist=None*, *weight='weight'*)

Return adjacency matrix of G.

Parameters

- **G** (*graph*) – A NetworkX graph
- **nodelist** (*list, optional*) – The rows and columns are ordered according to the nodes in nodelist. If nodelist is None, then the ordering is produced by G.nodes().
- **weight** (*string or None, optional (default='weight')*) – The edge data key used to provide each value in the matrix. If None, then each edge has weight 1.

Returns **A** – Adjacency matrix representation of G.

Return type SciPy sparse matrix

Notes

For directed graphs, entry *i,j* corresponds to an edge from *i* to *j*.

If you want a pure Python adjacency matrix representation try `networkx.convert.to_dict_of_dicts` which will return a dictionary-of-dictionaries format that can be addressed as a sparse matrix.

For MultiGraph/MultiDiGraph with parallel edges the weights are summed. See `to_numpy_matrix` for other options.

The convention used for self-loop edges in graphs is to assign the diagonal matrix entry value to the edge weight attribute (or the number 1 if the edge has no weight attribute). If the alternate convention of doubling the edge weight is desired the resulting SciPy sparse matrix can be modified as follows:

```
>>> import scipy as sp
>>> G = nx.Graph([(1,1)])
>>> A = nx.adjacency_matrix(G)
```

```
>>> print (A.todense())
[[1]]
>>> A.setdiag(A.diagonal()*2)
>>> print (A.todense())
[[2]]
```

See also:

`to_numpy_matrix()`, `to_scipy_sparse_matrix()`, `to_dict_of_dicts()`

7.1.2 incidence_matrix

incidence_matrix (*G*, *nodelist=None*, *edgelist=None*, *oriented=False*, *weight=None*)

Return incidence matrix of *G*.

The incidence matrix assigns each row to a node and each column to an edge. For a standard incidence matrix a 1 appears wherever a row's node is incident on the column's edge. For an oriented incidence matrix each edge is assigned an orientation (arbitrarily for undirected and aligning to direction for directed). A -1 appears for the tail of an edge and 1 for the head of the edge. The elements are zero otherwise.

Parameters

- **G** (*graph*) – A NetworkX graph
- **nodelist** (*list, optional (default= all nodes in G)*) – The rows are ordered according to the nodes in *nodelist*. If *nodelist* is *None*, then the ordering is produced by *G.nodes()*.
- **edgelist** (*list, optional (default= all edges in G)*) – The columns are ordered according to the edges in *edgelist*. If *edgelist* is *None*, then the ordering is produced by *G.edges()*.
- **oriented** (*bool, optional (default=False)*) – If *True*, matrix elements are +1 or -1 for the head or tail node respectively of each edge. If *False*, +1 occurs at both nodes.
- **weight** (*string or None, optional (default=None)*) – The edge data key used to provide each value in the matrix. If *None*, then each edge has weight 1. Edge weights, if used, should be positive so that the orientation can provide the sign.

Returns **A** – The incidence matrix of *G*.

Return type SciPy sparse matrix

Notes

For MultiGraph/MultiDiGraph, the edges in *edgelist* should be (u,v,key) 3-tuples.

“Networks are the best discrete model for so many problems in applied mathematics”¹.

References

7.2 Laplacian Matrix

Laplacian matrix of graphs.

`laplacian_matrix(G[, nodelist, weight])`

Return the Laplacian matrix of *G*.

Continued on next page

¹ Gil Strang, Network applications: A = incidence matrix, <http://academicearth.org/lectures/network-applications-incidence-matrix>

Table 7.2 – continued from previous page

<code>normalized_laplacian_matrix(G[, nodelist, ...])</code>	Return the normalized Laplacian matrix of G.
<code>directed_laplacian_matrix(G[, nodelist, ...])</code>	Return the directed Laplacian matrix of G.

7.2.1 laplacian_matrix

laplacian_matrix (*G*, *nodelist=None*, *weight='weight'*)

Return the Laplacian matrix of G.

The graph Laplacian is the matrix $L = D - A$, where A is the adjacency matrix and D is the diagonal matrix of node degrees.

Parameters

- **G** (*graph*) – A NetworkX graph
- **nodelist** (*list, optional*) – The rows and columns are ordered according to the nodes in nodelist. If nodelist is None, then the ordering is produced by G.nodes().
- **weight** (*string or None, optional (default='weight')*) – The edge data key used to compute each value in the matrix. If None, then each edge has weight 1.

Returns L – The Laplacian matrix of G.

Return type SciPy sparse matrix

Notes

For MultiGraph/MultiDiGraph, the edges weights are summed.

See also:

`to_numpy_matrix()`, `normalized_laplacian_matrix()`

7.2.2 normalized_laplacian_matrix

normalized_laplacian_matrix (*G*, *nodelist=None*, *weight='weight'*)

Return the normalized Laplacian matrix of G.

The normalized graph Laplacian is the matrix

$$N = D^{-1/2} L D^{-1/2}$$

where L is the graph Laplacian and D is the diagonal matrix of node degrees.

Parameters

- **G** (*graph*) – A NetworkX graph
- **nodelist** (*list, optional*) – The rows and columns are ordered according to the nodes in nodelist. If nodelist is None, then the ordering is produced by G.nodes().
- **weight** (*string or None, optional (default='weight')*) – The edge data key used to compute each value in the matrix. If None, then each edge has weight 1.

Returns N – The normalized Laplacian matrix of G.

Return type NumPy matrix

Notes

For MultiGraph/MultiDiGraph, the edges weights are summed. See `to_numpy_matrix` for other options.

If the Graph contains selfloops, D is defined as $\text{diag}(\text{sum}(A,1))$, where A is the adjacency matrix ².

See also:

`laplacian_matrix()`

References

7.2.3 directed_laplacian_matrix

directed_laplacian_matrix(*G*, *nodelist=None*, *weight='weight'*, *walk_type=None*, *alpha=0.95*)

Return the directed Laplacian matrix of *G*.

The graph directed Laplacian is the matrix

$$L = I - (\Phi^{1/2} P \Phi^{-1/2} + \Phi^{-1/2} P^T \Phi^{1/2})/2$$

where I is the identity matrix, P is the transition matrix of the graph, and Φ a matrix with the Perron vector of P in the diagonal and zeros elsewhere.

Depending on the value of *walk_type*, P can be the transition matrix induced by a random walk, a lazy random walk, or a random walk with teleportation (PageRank).

Parameters

- **G** (**DiGraph**) – A NetworkX graph
- **nodelist** (*list, optional*) – The rows and columns are ordered according to the nodes in *nodelist*. If *nodelist* is *None*, then the ordering is produced by *G.nodes()*.
- **weight** (*string or None, optional (default='weight')*) – The edge data key used to compute each value in the matrix. If *None*, then each edge has weight 1.
- **walk_type** (*string or None, optional (default=None)*) – If *None*, P is selected depending on the properties of the graph. Otherwise is one of 'random', 'lazy', or 'pagerank'
- **alpha** (*real*) – (1 - alpha) is the teleportation probability used with pagerank

Returns **L** – Normalized Laplacian of *G*.

Return type NumPy array

Raises

- **NetworkXError** – If NumPy cannot be imported
- **NetworkXNotImplemented** – If *G* is not a DiGraph

Notes

Only implemented for DiGraphs

See also:

`laplacian_matrix()`

² Steve Butler, Interlacing For Weighted Graphs Using The Normalized Laplacian, Electronic Journal of Linear Algebra, Volume 16, pp. 90-98, March 2007.

References

7.3 Spectrum

Eigenvalue spectrum of graphs.

<code>laplacian_spectrum(G[, weight])</code>	Return eigenvalues of the Laplacian of G
<code>adjacency_spectrum(G[, weight])</code>	Return eigenvalues of the adjacency matrix of G.

7.3.1 laplacian_spectrum

`laplacian_spectrum(G, weight='weight')`

Return eigenvalues of the Laplacian of G

Parameters

- **G** (*graph*) – A NetworkX graph
- **weight** (*string or None, optional (default='weight')*) – The edge data key used to compute each value in the matrix. If None, then each edge has weight 1.

Returns `evals` – Eigenvalues

Return type NumPy array

Notes

For MultiGraph/MultiDiGraph, the edges weights are summed. See `to_numpy_matrix` for other options.

See also:

`laplacian_matrix()`

7.3.2 adjacency_spectrum

`adjacency_spectrum(G, weight='weight')`

Return eigenvalues of the adjacency matrix of G.

Parameters

- **G** (*graph*) – A NetworkX graph
- **weight** (*string or None, optional (default='weight')*) – The edge data key used to compute each value in the matrix. If None, then each edge has weight 1.

Returns `evals` – Eigenvalues

Return type NumPy array

Notes

For MultiGraph/MultiDiGraph, the edges weights are summed. See `to_numpy_matrix` for other options.

See also:

`adjacency_matrix()`

7.4 Algebraic Connectivity

Algebraic connectivity and Fiedler vectors of undirected graphs.

<code>algebraic_connectivity</code> (G[, weight, ...])	Return the algebraic connectivity of an undirected graph.
<code>fiedler_vector</code> (G[, weight, normalized, tol, ...])	Return the Fiedler vector of a connected undirected graph.
<code>spectral_ordering</code> (G[, weight, normalized, ...])	Compute the spectral_ordering of a graph.

7.4.1 algebraic_connectivity

algebraic_connectivity (G, weight='weight', normalized=False, tol=1e-08, method='tracemin')

Return the algebraic connectivity of an undirected graph.

The algebraic connectivity of a connected undirected graph is the second smallest eigenvalue of its Laplacian matrix.

Parameters

- **G** (*NetworkX graph*) – An undirected graph.
- **weight** (*object, optional*) – The data key used to determine the weight of each edge. If None, then each edge has unit weight. Default value: None.
- **normalized** (*bool, optional*) – Whether the normalized Laplacian matrix is used. Default value: False.
- **tol** (*float, optional*) – Tolerance of relative residual in eigenvalue computation. Default value: 1e-8.
- **method** (*string, optional*) – Method of eigenvalue computation. It should be one of 'tracemin' (TraceMIN), 'lanczos' (Lanczos iteration) and 'lobpcg' (LOBPCG). Default value: 'tracemin'.

The TraceMIN algorithm uses a linear system solver. The following values allow specifying the solver to be used.

Value	Solver
'tracemin_pcg'	Preconditioned conjugate gradient method
'tracemin_chol'	Cholesky factorization
'tracemin_lu'	LU factorization

Returns algebraic_connectivity – Algebraic connectivity.

Return type float

Raises

- `NetworkXNotImplemented` – If G is directed.
- `NetworkXError` – If G has less than two nodes.

Notes

Edge weights are interpreted by their absolute values. For MultiGraph's, weights of parallel edges are summed. Zero-weighted edges are ignored.

To use Cholesky factorization in the TraceMIN algorithm, the `scikits.sparse` package must be installed.

See also:

```
laplacian_matrix()
```

7.4.2 fiedler_vector

fiedler_vector (*G*, *weight*='weight', *normalized*=False, *tol*=1e-08, *method*='tracemin')

Return the Fiedler vector of a connected undirected graph.

The Fiedler vector of a connected undirected graph is the eigenvector corresponding to the second smallest eigenvalue of the Laplacian matrix of the graph.

Parameters

- **G** (*NetworkX graph*) – An undirected graph.
- **weight** (*object, optional*) – The data key used to determine the weight of each edge. If None, then each edge has unit weight. Default value: None.
- **normalized** (*bool, optional*) – Whether the normalized Laplacian matrix is used. Default value: False.
- **tol** (*float, optional*) – Tolerance of relative residual in eigenvalue computation. Default value: 1e-8.
- **method** (*string, optional*) – Method of eigenvalue computation. It should be one of 'tracemin' (TraceMIN), 'lanczos' (Lanczos iteration) and 'lobpcg' (LOBPCG). Default value: 'tracemin'.

The TraceMIN algorithm uses a linear system solver. The following values allow specifying the solver to be used.

Value	Solver
'tracemin_pcg'	Preconditioned conjugate gradient method
'tracemin_chol'	Cholesky factorization
'tracemin_lu'	LU factorization

Returns **fiedler_vector** – Fiedler vector.

Return type NumPy array of floats.

Raises

- **NetworkXNotImplemented** – If *G* is directed.
- **NetworkXError** – If *G* has less than two nodes or is not connected.

Notes

Edge weights are interpreted by their absolute values. For MultiGraph's, weights of parallel edges are summed. Zero-weighted edges are ignored.

To use Cholesky factorization in the TraceMIN algorithm, the `scikits.sparse` package must be installed.

See also:

```
laplacian_matrix()
```

7.4.3 spectral_ordering

spectral_ordering (*G*, *weight*='weight', *normalized*=False, *tol*=1e-08, *method*='tracemin')

Compute the spectral_ordering of a graph.

The spectral ordering of a graph is an ordering of its nodes where nodes in the same weakly connected components appear contiguous and ordered by their corresponding elements in the Fiedler vector of the component.

Parameters

- **G** (*NetworkX graph*) – A graph.
- **weight** (*object, optional*) – The data key used to determine the weight of each edge. If None, then each edge has unit weight. Default value: None.
- **normalized** (*bool, optional*) – Whether the normalized Laplacian matrix is used. Default value: False.
- **tol** (*float, optional*) – Tolerance of relative residual in eigenvalue computation. Default value: 1e-8.
- **method** (*string, optional*) – Method of eigenvalue computation. It should be one of 'tracemin' (TraceMIN), 'lanczos' (Lanczos iteration) and 'lobpcg' (LOBPCG). Default value: 'tracemin'.

The TraceMIN algorithm uses a linear system solver. The following values allow specifying the solver to be used.

Value	Solver
'tracemin_pcg'	Preconditioned conjugate gradient method
'tracemin_chol'	Cholesky factorization
'tracemin_lu'	LU factorization

Returns **spectral_ordering** – Spectral ordering of nodes.

Return type NumPy array of floats.

Raises `NetworkXError` – If G is empty.

Notes

Edge weights are interpreted by their absolute values. For `MultiGraph`'s, weights of parallel edges are summed. Zero-weighted edges are ignored.

To use Cholesky factorization in the TraceMIN algorithm, the `scikits.sparse` package must be installed.

See also:

`laplacian_matrix()`

7.5 Attribute Matrices

Functions for constructing matrix-like objects from graph attributes.

<code>attr_matrix(G[, edge_attr, node_attr, ...])</code>	Returns a NumPy matrix using attributes from G.
<code>attr_sparse_matrix(G[, edge_attr, ...])</code>	Returns a SciPy sparse matrix using attributes from G.

7.5.1 attr_matrix

attr_matrix (*G*, *edge_attr=None*, *node_attr=None*, *normalized=False*, *rc_order=None*, *dtype=None*, *order=None*)

Returns a NumPy matrix using attributes from *G*.

If only *G* is passed in, then the adjacency matrix is constructed.

Let *A* be a discrete set of values for the node attribute *node_attr*. Then the elements of *A* represent the rows and columns of the constructed matrix. Now, iterate through every edge *e*=(*u*,*v*) in *G* and consider the value of the edge attribute *edge_attr*. If *ua* and *va* are the values of the node attribute *node_attr* for *u* and *v*, respectively, then the value of the edge attribute is added to the matrix element at (*ua*, *va*).

Parameters

- **G** (*graph*) – The NetworkX graph used to construct the NumPy matrix.
- **edge_attr** (*str*, *optional*) – Each element of the matrix represents a running total of the specified edge attribute for edges whose node attributes correspond to the rows/cols of the matrix. The attribute must be present for all edges in the graph. If no attribute is specified, then we just count the number of edges whose node attributes correspond to the matrix element.
- **node_attr** (*str*, *optional*) – Each row and column in the matrix represents a particular value of the node attribute. The attribute must be present for all nodes in the graph. Note, the values of this attribute should be reliably hashable. So, float values are not recommended. If no attribute is specified, then the rows and columns will be the nodes of the graph.
- **normalized** (*bool*, *optional*) – If True, then each row is normalized by the summation of its values.
- **rc_order** (*list*, *optional*) – A list of the node attribute values. This list specifies the ordering of rows and columns of the array. If no ordering is provided, then the ordering will be random (and also, a return value).

Other Parameters

- **dtype** (*NumPy data-type*, *optional*) – A valid NumPy dtype used to initialize the array. Keep in mind certain dtypes can yield unexpected results if the array is to be normalized. The parameter is passed to `numpy.zeros()`. If unspecified, the NumPy default is used.
- **order** (*{'C', 'F'}*, *optional*) – Whether to store multidimensional data in C- or Fortran-contiguous (row- or column-wise) order in memory. This parameter is passed to `numpy.zeros()`. If unspecified, the NumPy default is used.

Returns

- **M** (*NumPy matrix*) – The attribute matrix.
- **ordering** (*list*) – If *rc_order* was specified, then only the matrix is returned. However, if *rc_order* was None, then the ordering used to construct the matrix is returned as well.

Examples

Construct an adjacency matrix:

```
>>> G = nx.Graph()
>>> G.add_edge(0,1,thickness=1,weight=3)
>>> G.add_edge(0,2,thickness=2)
>>> G.add_edge(1,2,thickness=3)
>>> nx.attr_matrix(G, rc_order=[0,1,2])
```

```
matrix([[ 0.,  1.,  1.],
        [ 1.,  0.,  1.],
        [ 1.,  1.,  0.]])
```

Alternatively, we can obtain the matrix describing edge thickness.

```
>>> nx.attr_matrix(G, edge_attr='thickness', rc_order=[0,1,2])
matrix([[ 0.,  1.,  2.],
        [ 1.,  0.,  3.],
        [ 2.,  3.,  0.]])
```

We can also color the nodes and ask for the probability distribution over all edges (u,v) describing:

$\Pr(v \text{ has color } Y \mid u \text{ has color } X)$

```
>>> G.node[0]['color'] = 'red'
>>> G.node[1]['color'] = 'red'
>>> G.node[2]['color'] = 'blue'
>>> rc = ['red', 'blue']
>>> nx.attr_matrix(G, node_attr='color', normalized=True, rc_order=rc)
matrix([[ 0.33333333,  0.66666667],
        [ 1.,          0.          ]])
```

For example, the above tells us that for all edges (u,v):

$\Pr(v \text{ is red} \mid u \text{ is red}) = 1/3$ $\Pr(v \text{ is blue} \mid u \text{ is red}) = 2/3$

$\Pr(v \text{ is red} \mid u \text{ is blue}) = 1$ $\Pr(v \text{ is blue} \mid u \text{ is blue}) = 0$

Finally, we can obtain the total weights listed by the node colors.

```
>>> nx.attr_matrix(G, edge_attr='weight', node_attr='color', rc_order=rc)
matrix([[ 3.,  2.],
        [ 2.,  0.]])
```

Thus, the total weight over all edges (u,v) with u and v having colors:

(red, red) is 3 # the sole contribution is from edge (0,1) (red, blue) is 2 # contributions from edges (0,2) and (1,2) (blue, red) is 2 # same as (red, blue) since graph is undirected (blue, blue) is 0 # there are no edges with blue endpoints

7.5.2 attr_sparse_matrix

attr_sparse_matrix(*G*, *edge_attr=None*, *node_attr=None*, *normalized=False*, *rc_order=None*, *dtype=None*)

Returns a SciPy sparse matrix using attributes from *G*.

If only *G* is passed in, then the adjacency matrix is constructed.

Let *A* be a discrete set of values for the node attribute *node_attr*. Then the elements of *A* represent the rows and columns of the constructed matrix. Now, iterate through every edge *e*=(u,v) in *G* and consider the value of the edge attribute *edge_attr*. If *ua* and *va* are the values of the node attribute *node_attr* for *u* and *v*, respectively, then the value of the edge attribute is added to the matrix element at (*ua*, *va*).

Parameters

- **G** (*graph*) – The NetworkX graph used to construct the NumPy matrix.
- **edge_attr** (*str*, *optional*) – Each element of the matrix represents a running total of the specified edge attribute for edges whose node attributes correspond to the rows/cols of the matrix. The attribute must be present for all edges in the graph. If no attribute is specified,

then we just count the number of edges whose node attributes correspond to the matrix element.

- **node_attr** (*str, optional*) – Each row and column in the matrix represents a particular value of the node attribute. The attribute must be present for all nodes in the graph. Note, the values of this attribute should be reliably hashable. So, float values are not recommended. If no attribute is specified, then the rows and columns will be the nodes of the graph.
- **normalized** (*bool, optional*) – If True, then each row is normalized by the summation of its values.
- **rc_order** (*list, optional*) – A list of the node attribute values. This list specifies the ordering of rows and columns of the array. If no ordering is provided, then the ordering will be random (and also, a return value).

Other Parameters **dtype** (*NumPy data-type, optional*) – A valid NumPy dtype used to initialize the array. Keep in mind certain dtypes can yield unexpected results if the array is to be normalized. The parameter is passed to `numpy.zeros()`. If unspecified, the NumPy default is used.

Returns

- **M** (*SciPy sparse matrix*) – The attribute matrix.
- **ordering** (*list*) – If *rc_order* was specified, then only the matrix is returned. However, if *rc_order* was None, then the ordering used to construct the matrix is returned as well.

Examples

Construct an adjacency matrix:

```
>>> G = nx.Graph()
>>> G.add_edge(0,1,thickness=1,weight=3)
>>> G.add_edge(0,2,thickness=2)
>>> G.add_edge(1,2,thickness=3)
>>> M = nx.attr_sparse_matrix(G, rc_order=[0,1,2])
>>> M.todense()
matrix([[ 0.,  1.,  1.],
        [ 1.,  0.,  1.],
        [ 1.,  1.,  0.]])
```

Alternatively, we can obtain the matrix describing edge thickness.

```
>>> M = nx.attr_sparse_matrix(G, edge_attr='thickness', rc_order=[0,1,2])
>>> M.todense()
matrix([[ 0.,  1.,  2.],
        [ 1.,  0.,  3.],
        [ 2.,  3.,  0.]])
```

We can also color the nodes and ask for the probability distribution over all edges (u,v) describing:

$\Pr(v \text{ has color } Y \mid u \text{ has color } X)$

```
>>> G.node[0]['color'] = 'red'
>>> G.node[1]['color'] = 'red'
>>> G.node[2]['color'] = 'blue'
>>> rc = ['red', 'blue']
>>> M = nx.attr_sparse_matrix(G, node_attr='color',
>>> M.todense()
matrix([[ 0.33333333,  0.66666667],
        [ 1.,          ,  0.          ]])
```

normalized

For example, the above tells us that for all edges (u,v):

$$\Pr(v \text{ is red} \mid u \text{ is red}) = 1/3 \quad \Pr(v \text{ is blue} \mid u \text{ is red}) = 2/3$$

$$\Pr(v \text{ is red} \mid u \text{ is blue}) = 1 \quad \Pr(v \text{ is blue} \mid u \text{ is blue}) = 0$$

Finally, we can obtain the total weights listed by the node colors.

```
>>> M = nx.attr_sparse_matrix(G, edge_attr='weight',
>>> M.todense()
matrix([[ 3.,  2.],
        [ 2.,  0.]])
```

node_attr=

Thus, the total weight over all edges (u,v) with u and v having colors:

(red, red) is 3 # the sole contribution is from edge (0,1) (red, blue) is 2 # contributions from edges (0,2) and (1,2) (blue, red) is 2 # same as (red, blue) since graph is undirected (blue, blue) is 0 # there are no edges with blue endpoints

CONVERTING TO AND FROM OTHER DATA FORMATS

8.1 To NetworkX Graph

Functions to convert NetworkX graphs to and from other formats.

The preferred way of converting data to a NetworkX graph is through the graph constructor. The constructor calls the `to_networkx_graph()` function which attempts to guess the input type and convert it automatically.

Examples

Create a graph with a single edge from a dictionary of dictionaries

```
>>> d={0: {1: 1}} # dict-of-dicts single edge (0,1)
>>> G=nx.Graph(d)
```

See also:

`nx_pygraphviz`, `nx_pydot`

`to_networkx_graph(data[, create_using, ...])` Make a NetworkX graph from a known data structure.

8.1.1 to_networkx_graph

to_networkx_graph (*data*, *create_using=None*, *multigraph_input=False*)

Make a NetworkX graph from a known data structure.

The preferred way to call this is automatically from the class constructor

```
>>> d={0: {1: {'weight':1}}} # dict-of-dicts single edge (0,1)
>>> G=nx.Graph(d)
```

instead of the equivalent

```
>>> G=nx.from_dict_of_dicts(d)
```

Parameters

- **data** (*a object to be converted*) – Current known types are: any NetworkX graph dict-of-dicts dist-of-lists list of edges numpy matrix numpy ndarray scipy sparse matrix pygraphviz agraph
- **create_using** (*NetworkX graph*) – Use specified graph for result. Otherwise a new graph is created.

- **multigraph_input** (*bool (default False)*) – If True and data is a dict_of_dicts, try to create a multigraph assuming dict_of_dict_of_lists. If data and create_using are both multigraphs then create a multigraph from a multigraph.

8.2 Dictionaries

<code>to_dict_of_dicts(G[, nodelist, edge_data])</code>	Return adjacency representation of graph as a dictionary of dictionaries.
<code>from_dict_of_dicts(d[, create_using, ...])</code>	Return a graph from a dictionary of dictionaries.

8.2.1 to_dict_of_dicts

to_dict_of_dicts (*G, nodelist=None, edge_data=None*)

Return adjacency representation of graph as a dictionary of dictionaries.

Parameters

- **G** (*graph*) – A NetworkX graph
- **nodelist** (*list*) – Use only nodes specified in nodelist
- **edge_data** (*list, optional*) – If provided, the value of the dictionary will be set to edge_data for all edges. This is useful to make an adjacency matrix type representation with 1 as the edge data. If edgedata is None, the edgedata in G is used to fill the values. If G is a multigraph, the edgedata is a dict for each pair (u,v).

8.2.2 from_dict_of_dicts

from_dict_of_dicts (*d, create_using=None, multigraph_input=False*)

Return a graph from a dictionary of dictionaries.

Parameters

- **d** (*dictionary of dictionaries*) – A dictionary of dictionaries adjacency representation.
- **create_using** (*NetworkX graph*) – Use specified graph for result. Otherwise a new graph is created.
- **multigraph_input** (*bool (default False)*) – When True, the values of the inner dict are assumed to be containers of edge data for multiple edges. Otherwise this routine assumes the edge data are singletons.

Examples

```
>>> dod= {0: {1:{'weight':1}}} # single edge (0,1)
>>> G=nx.from_dict_of_dicts(dod)
```

or >>> G=nx.Graph(dod) # use Graph constructor

8.3 Lists

<code>to_dict_of_lists(G[, nodelist])</code>	Return adjacency representation of graph as a dictionary of lists.
<code>from_dict_of_lists(d[, create_using])</code>	Return a graph from a dictionary of lists.
<code>to_edgelist(G[, nodelist])</code>	Return a list of edges in the graph.
<code>from_edgelist(edgelist[, create_using])</code>	Return a graph from a list of edges.

8.3.1 to_dict_of_lists

to_dict_of_lists (*G*, *nodelist=None*)

Return adjacency representation of graph as a dictionary of lists.

Parameters

- **G** (*graph*) – A NetworkX graph
- **nodelist** (*list*) – Use only nodes specified in nodelist

Notes

Completely ignores edge data for MultiGraph and MultiDiGraph.

8.3.2 from_dict_of_lists

from_dict_of_lists (*d*, *create_using=None*)

Return a graph from a dictionary of lists.

Parameters

- **d** (*dictionary of lists*) – A dictionary of lists adjacency representation.
- **create_using** (*NetworkX graph*) – Use specified graph for result. Otherwise a new graph is created.

Examples

```
>>> dol= {0:[1]} # single edge (0,1)
>>> G=nx.from_dict_of_lists(dol)
```

or >>> G=nx.Graph(dol) # use Graph constructor

8.3.3 to_edgelist

to_edgelist (*G*, *nodelist=None*)

Return a list of edges in the graph.

Parameters

- **G** (*graph*) – A NetworkX graph
- **nodelist** (*list*) – Use only nodes specified in nodelist

8.3.4 from_edgelist

from_edgelist (*edgelist*, *create_using=None*)

Return a graph from a list of edges.

Parameters

- **edgelist** (*list or iterator*) – Edge tuples
- **create_using** (*NetworkX graph*) – Use specified graph for result. Otherwise a new graph is created.

Examples

```
>>> edgelist= [(0,1)] # single edge (0,1)
>>> G=nx.from_edgelist(edgelist)
```

or >>> G=nx.Graph(edgelist) # use Graph constructor

8.4 Numpy

Functions to convert NetworkX graphs to and from numpy/scipy matrices.

The preferred way of converting data to a NetworkX graph is through the graph constructor. The constructor calls the `to_networkx_graph()` function which attempts to guess the input type and convert it automatically.

Examples

Create a 10 node random graph from a numpy matrix

```
>>> import numpy
>>> a = numpy.reshape(numpy.random.random_integers(0,1,size=100), (10,10))
>>> D = nx.DiGraph(a)
```

or equivalently

```
>>> D = nx.to_networkx_graph(a,create_using=nx.DiGraph())
```

See also:

`nx_pygraphviz`, `nx_pydot`

<code>to_numpy_matrix</code> (<i>G</i> [, <i>odelist</i> , <i>dtype</i> , <i>order</i> , ...])	Return the graph adjacency matrix as a NumPy matrix.
<code>to_numpy_recarray</code> (<i>G</i> [, <i>odelist</i> , <i>dtype</i> , <i>order</i>])	Return the graph adjacency matrix as a NumPy recarray.
<code>from_numpy_matrix</code> (<i>A</i> [, <i>parallel_edges</i> , ...])	Return a graph from numpy matrix.

8.4.1 to_numpy_matrix

to_numpy_matrix (*G*, *odelist=None*, *dtype=None*, *order=None*, *multigraph_weight=<built-in function sum>*, *weight='weight'*, *nonedge=0.0*)

Return the graph adjacency matrix as a NumPy matrix.

Parameters

- **G** (*graph*) – The NetworkX graph used to construct the NumPy matrix.
- **odelist** (*list, optional*) – The rows and columns are ordered according to the nodes in `odelist`. If `odelist` is `None`, then the ordering is produced by `G.nodes()`.
- **dtype** (*NumPy data type, optional*) – A valid single NumPy data type used to initialize the array. This must be a simple type such as `int` or `numpy.float64` and not a compound data type (see `to_numpy_recarray`) If `None`, then the NumPy default is used.
- **order** (*{‘C’, ‘F’}, optional*) – Whether to store multidimensional data in C- or Fortran-contiguous (row- or column-wise) order in memory. If `None`, then the NumPy default is used.
- **multigraph_weight** (*{sum, min, max}, optional*) – An operator that determines how weights in multigraphs are handled. The default is to sum the weights of the multiple edges.
- **weight** (*string or None optional (default = ‘weight’)*) – The edge attribute that holds the numerical value used for the edge weight. If an edge does not have that attribute, then the value 1 is used instead.
- **nonedge** (*float (default = 0.0)*) – The matrix values corresponding to nonedges are typically set to zero. However, this could be undesirable if there are matrix values corresponding to actual edges that also have the value zero. If so, one might prefer nonedges to have some other value, such as `nan`.

Returns **M** – Graph adjacency matrix

Return type NumPy matrix

See also:

`to_numpy_recarray()`, `from_numpy_matrix()`

Notes

The matrix entries are assigned to the weight edge attribute. When an edge does not have a weight attribute, the value of the entry is set to the number 1. For multiple (parallel) edges, the values of the entries are determined by the `multigraph_weight` parameter. The default is to sum the weight attributes for each of the parallel edges.

When `odelist` does not contain every node in `G`, the matrix is built from the subgraph of `G` that is induced by the nodes in `odelist`.

The convention used for self-loop edges in graphs is to assign the diagonal matrix entry value to the weight attribute of the edge (or the number 1 if the edge has no weight attribute). If the alternate convention of doubling the edge weight is desired the resulting NumPy matrix can be modified as follows:

```
>>> import numpy as np
>>> G = nx.Graph([(1, 1)])
>>> A = nx.to_numpy_matrix(G)
>>> A
matrix([[ 1.]])
>>> A.A[np.diag_indices_from(A)] *= 2
>>> A
matrix([[ 2.]])
```

Examples

```
>>> G = nx.MultiDiGraph()
>>> G.add_edge(0,1,weight=2)
>>> G.add_edge(1,0)
>>> G.add_edge(2,2,weight=3)
>>> G.add_edge(2,2)
>>> nx.to_numpy_matrix(G, nodelist=[0,1,2])
matrix([[ 0.,  2.,  0.],
        [ 1.,  0.,  0.],
        [ 0.,  0.,  4.]])
```

8.4.2 to_numpy_recarray

to_numpy_recarray (*G*, *nodelist=None*, *dtype=[('weight', <type 'float'>)]*, *order=None*)

Return the graph adjacency matrix as a NumPy recarray.

Parameters

- **G** (*graph*) – The NetworkX graph used to construct the NumPy matrix.
- **nodelist** (*list, optional*) – The rows and columns are ordered according to the nodes in *nodelist*. If *nodelist* is None, then the ordering is produced by *G.nodes()*.
- **dtype** (*NumPy data-type, optional*) – A valid NumPy named dtype used to initialize the NumPy recarray. The data type names are assumed to be keys in the graph edge attribute dictionary.
- **order** (*{'C', 'F'}, optional*) – Whether to store multidimensional data in C- or Fortran-contiguous (row- or column-wise) order in memory. If None, then the NumPy default is used.

Returns **M** – The graph with specified edge data as a Numpy recarray

Return type NumPy recarray

Notes

When *nodelist* does not contain every node in *G*, the matrix is built from the subgraph of *G* that is induced by the nodes in *nodelist*.

Examples

```
>>> G = nx.Graph()
>>> G.add_edge(1,2,weight=7.0,cost=5)
>>> A=nx.to_numpy_recarray(G,dtype=[('weight',float),('cost',int)])
>>> print(A.weight)
[[ 0.  7.]
 [ 7.  0.]]
>>> print(A.cost)
[[0 5]
 [5 0]]
```

8.4.3 from_numpy_matrix

from_numpy_matrix (*A*, *parallel_edges=False*, *create_using=None*)

Return a graph from numpy matrix.

The numpy matrix is interpreted as an adjacency matrix for the graph.

Parameters

- **A** (*numpy matrix*) – An adjacency matrix representation of a graph
- **parallel_edges** (*Boolean*) – If this is `True`, *create_using* is a multigraph, and *A* is an integer matrix, then entry (i, j) in the matrix is interpreted as the number of parallel edges joining vertices i and j in the graph. If it is `False`, then the entries in the adjacency matrix are interpreted as the weight of a single edge joining the vertices.
- **create_using** (*NetworkX graph*) – Use specified graph for result. The default is `Graph()`

Notes

If *create_using* is an instance of `networkx.MultiGraph` or `networkx.MultiDiGraph`, *parallel_edges* is `True`, and the entries of *A* are of type `int`, then this function returns a multigraph (of the same type as *create_using*) with parallel edges.

If *create_using* is an undirected multigraph, then only the edges indicated by the upper triangle of the matrix *A* will be added to the graph.

If the numpy matrix has a single data type for each matrix entry it will be converted to an appropriate Python data type.

If the numpy matrix has a user-specified compound data type the names of the data fields will be used as attribute keys in the resulting NetworkX graph.

See also:

`to_numpy_matrix()`, `to_numpy_recarray()`

Examples

Simple integer weights on edges:

```
>>> import numpy
>>> A=numpy.matrix([[1, 1], [2, 1]])
>>> G=nx.from_numpy_matrix(A)
```

If *create_using* is a multigraph and the matrix has only integer entries, the entries will be interpreted as weighted edges joining the vertices (without creating parallel edges):

```
>>> import numpy
>>> A = numpy.matrix([[1, 1], [1, 2]])
>>> G = nx.from_numpy_matrix(A, create_using = nx.MultiGraph())
>>> G[1][1]
{0: {'weight': 2}}
```

If *create_using* is a multigraph and the matrix has only integer entries but *parallel_edges* is `True`, then the entries will be interpreted as the number of parallel edges joining those two vertices:

```
>>> import numpy
>>> A = numpy.matrix([[1, 1], [1, 2]])
>>> temp = nx.MultiGraph()
>>> G = nx.from_numpy_matrix(A, parallel_edges = True, create_using = temp)
>>> G[1][1]
{0: {'weight': 1}, 1: {'weight': 1}}
```

User defined compound data type on edges:

```
>>> import numpy
>>> dt = [('weight', float), ('cost', int)]
>>> A = numpy.matrix([[1.0, 2]], dtype = dt)
>>> G = nx.from_numpy_matrix(A)
>>> G.edges()
[(0, 0)]
>>> G[0][0]['cost']
2
>>> G[0][0]['weight']
1.0
```

8.5 Scipy

<code>to_scipy_sparse_matrix(G[, nodelist, dtype, ...])</code>	Return the graph adjacency matrix as a SciPy sparse matrix.
<code>from_scipy_sparse_matrix(A[, ...])</code>	Creates a new graph from an adjacency matrix given as a SciPy sparse matrix.

8.5.1 to_scipy_sparse_matrix

to_scipy_sparse_matrix (*G*, *nodelist=None*, *dtype=None*, *weight='weight'*, *format='csr'*)

Return the graph adjacency matrix as a SciPy sparse matrix.

Parameters

- **G** (*graph*) – The NetworkX graph used to construct the NumPy matrix.
- **nodelist** (*list, optional*) – The rows and columns are ordered according to the nodes in *nodelist*. If *nodelist* is None, then the ordering is produced by *G.nodes()*.
- **dtype** (*NumPy data-type, optional*) – A valid NumPy dtype used to initialize the array. If None, then the NumPy default is used.
- **weight** (*string or None optional (default='weight')*) – The edge attribute that holds the numerical value used for the edge weight. If None then all edge weights are 1.
- **format** (*str in {'bsr', 'csr', 'csc', 'coo', 'lil', 'dia', 'dok'}*) – The type of the matrix to be returned (default 'csr'). For some algorithms different implementations of sparse matrices can perform better. See ¹ for details.

Returns **M** – Graph adjacency matrix.

Return type SciPy sparse matrix

¹ Scipy Dev. References, “Sparse Matrices”, <http://docs.scipy.org/doc/scipy/reference/sparse.html>

Notes

The matrix entries are populated using the edge attribute held in parameter `weight`. When an edge does not have that attribute, the value of the entry is 1.

For multiple edges the matrix values are the sums of the edge weights.

When *odelist* does not contain every node in G , the matrix is built from the subgraph of G that is induced by the nodes in *odelist*.

Uses `coo_matrix` format. To convert to other formats specify the `format=` keyword.

The convention used for self-loop edges in graphs is to assign the diagonal matrix entry value to the weight attribute of the edge (or the number 1 if the edge has no weight attribute). If the alternate convention of doubling the edge weight is desired the resulting SciPy sparse matrix can be modified as follows:

```
>>> import scipy as sp
>>> G = nx.Graph([(1,1)])
>>> A = nx.to_scipy_sparse_matrix(G)
>>> print(A.todense())
[[1]]
>>> A.setdiag(A.diagonal()*2)
>>> print(A.todense())
[[2]]
```

Examples

```
>>> G = nx.MultiDiGraph()
>>> G.add_edge(0,1,weight=2)
>>> G.add_edge(1,0)
>>> G.add_edge(2,2,weight=3)
>>> G.add_edge(2,2)
>>> S = nx.to_scipy_sparse_matrix(G, nodelist=[0,1,2])
>>> print(S.todense())
[[0 2 0]
 [1 0 0]
 [0 0 4]]
```

References

8.5.2 from_scipy_sparse_matrix

from_scipy_sparse_matrix (*A*, *parallel_edges=False*, *create_using=None*, *edge_attribute='weight'*)
Creates a new graph from an adjacency matrix given as a SciPy sparse matrix.

Parameters

- **A** (*scipy sparse matrix*) – An adjacency matrix representation of a graph
- **parallel_edges** (*Boolean*) – If this is `True`, *create_using* is a multigraph, and *A* is an integer matrix, then entry (i, j) in the matrix is interpreted as the number of parallel edges joining vertices i and j in the graph. If it is `False`, then the entries in the adjacency matrix are interpreted as the weight of a single edge joining the vertices.
- **create_using** (*NetworkX graph*) – Use specified graph for result. The default is `Graph()`

- **edge_attribute** (*string*) – Name of edge attribute to store matrix numeric value. The data will have the same type as the matrix entry (int, float, (real,imag)).

Notes

If *create_using* is an instance of `networkx.MultiGraph` or `networkx.MultiDiGraph`, *parallel_edges* is `True`, and the entries of *A* are of type `int`, then this function returns a multigraph (of the same type as *create_using*) with parallel edges. In this case, *edge_attribute* will be ignored.

If *create_using* is an undirected multigraph, then only the edges indicated by the upper triangle of the matrix *A* will be added to the graph.

Examples

```
>>> import scipy.sparse
>>> A = scipy.sparse.eye(2,2,1)
>>> G = nx.from_scipy_sparse_matrix(A)
```

If *create_using* is a multigraph and the matrix has only integer entries, the entries will be interpreted as weighted edges joining the vertices (without creating parallel edges):

```
>>> import scipy
>>> A = scipy.sparse.csr_matrix([[1, 1], [1, 2]])
>>> G = nx.from_scipy_sparse_matrix(A, create_using=nx.MultiGraph())
>>> G[1][1]
{0: {'weight': 2}}
```

If *create_using* is a multigraph and the matrix has only integer entries but *parallel_edges* is `True`, then the entries will be interpreted as the number of parallel edges joining those two vertices:

```
>>> import scipy
>>> A = scipy.sparse.csr_matrix([[1, 1], [1, 2]])
>>> G = nx.from_scipy_sparse_matrix(A, parallel_edges=True,
...                               create_using=nx.MultiGraph())
>>> G[1][1]
{0: {'weight': 1}, 1: {'weight': 1}}
```

8.6 Pandas

<code>to_pandas_dataframe(G[, nodelist, ...])</code>	Return the graph adjacency matrix as a Pandas DataFrame.
<code>from_pandas_dataframe(df, source, target[, ...])</code>	Return a graph from Pandas DataFrame.

8.6.1 to_pandas_dataframe

`to_pandas_dataframe` (*G*, *nodelist=None*, *multigraph_weight=<built-in function sum>*, *weight='weight'*, *nonedge=0.0*)

Return the graph adjacency matrix as a Pandas DataFrame.

Parameters

- *G* (*graph*) – The NetworkX graph used to construct the Pandas DataFrame.

- **nodelist** (*list, optional*) – The rows and columns are ordered according to the nodes in *nodelist*. If *nodelist* is *None*, then the ordering is produced by `G.nodes()`.
- **multigraph_weight** (*{sum, min, max}, optional*) – An operator that determines how weights in multigraphs are handled. The default is to sum the weights of the multiple edges.
- **weight** (*string or None, optional*) – The edge attribute that holds the numerical value used for the edge weight. If an edge does not have that attribute, then the value 1 is used instead.
- **nonedge** (*float, optional*) – The matrix values corresponding to nonedges are typically set to zero. However, this could be undesirable if there are matrix values corresponding to actual edges that also have the value zero. If so, one might prefer nonedges to have some other value, such as *nan*.

Returns `df` – Graph adjacency matrix

Return type Pandas DataFrame

Notes

The DataFrame entries are assigned to the weight edge attribute. When an edge does not have a weight attribute, the value of the entry is set to the number 1. For multiple (parallel) edges, the values of the entries are determined by the ‘multigraph_weight’ parameter. The default is to sum the weight attributes for each of the parallel edges.

When *nodelist* does not contain every node in *G*, the matrix is built from the subgraph of *G* that is induced by the nodes in *nodelist*.

The convention used for self-loop edges in graphs is to assign the diagonal matrix entry value to the weight attribute of the edge (or the number 1 if the edge has no weight attribute). If the alternate convention of doubling the edge weight is desired the resulting Pandas DataFrame can be modified as follows:

```
>>> import pandas as pd
>>> import numpy as np
>>> G = nx.Graph([(1,1)])
>>> df = nx.to_pandas_dataframe(G)
>>> df
   1
1  1
>>> df.values[np.diag_indices_from(df)] *= 2
>>> df
   1
1  2
```

Examples

```
>>> G = nx.MultiDiGraph()
>>> G.add_edge(0,1,weight=2)
>>> G.add_edge(1,0)
>>> G.add_edge(2,2,weight=3)
>>> G.add_edge(2,2)
>>> nx.to_pandas_dataframe(G, nodelist=[0,1,2])
   0  1  2
0  0  2  0
1  1  0  0
2  0  0  4
```

8.6.2 from_pandas_dataframe

from_pandas_dataframe (*df, source, target, edge_attr=None, create_using=None*)

Return a graph from Pandas DataFrame.

The Pandas DataFrame should contain at least two columns of node names and zero or more columns of node attributes. Each row will be processed as one edge instance.

Note: This function iterates over DataFrame.values, which is not guaranteed to retain the data type across columns in the row. This is only a problem if your row is entirely numeric and a mix of ints and floats. In that case, all values will be returned as floats. See the DataFrame.iterrows documentation for an example.

Parameters

- **df** (*Pandas DataFrame*) – An edge list representation of a graph
- **source** (*str or int*) – A valid column name (string or iteger) for the source nodes (for the directed case).
- **target** (*str or int*) – A valid column name (string or iteger) for the target nodes (for the directed case).
- **edge_attr** (*str or int, iterable, True*) – A valid column name (str or integer) or list of column names that will be used to retrieve items from the row and add them to the graph as edge attributes. If *True*, all of the remaining columns will be added.
- **create_using** (*NetworkX graph*) – Use specified graph for result. The default is Graph()

See also:

[`to_pandas_dataframe\(\)`](#)

Examples

Simple integer weights on edges:

```
>>> import pandas as pd
>>> import numpy as np
>>> r = np.random.RandomState(seed=5)
>>> ints = r.random_integers(1, 10, size=(3,2))
>>> a = ['A', 'B', 'C']
>>> b = ['D', 'A', 'E']
>>> df = pd.DataFrame(ints, columns=['weight', 'cost'])
>>> df[0] = a
>>> df['b'] = b
>>> df
   weight  cost  0  b
0        4     7  A  D
1        7     1  B  A
2       10     9  C  E
>>> G=nx.from_pandas_dataframe(df, 0, 'b', ['weight', 'cost'])
>>> G['E']['C']['weight']
10
>>> G['E']['C']['cost']
9
```


READING AND WRITING GRAPHS

9.1 Adjacency List

9.1.1 Adjacency List

Read and write NetworkX graphs as adjacency lists.

Adjacency list format is useful for graphs without data associated with nodes or edges and for nodes that can be meaningfully represented as strings.

Format

The adjacency list format consists of lines with node labels. The first label in a line is the source node. Further labels in the line are considered target nodes and are added to the graph along with an edge between the source node and target node.

The graph with edges a-b, a-c, d-e can be represented as the following adjacency list (anything following the # in a line is a comment):

```
a b c # source target target
d e
```

<code>read_adjlist(path[, comments, delimiter, ...])</code>	Read graph in adjacency list format from path.
<code>write_adjlist(G, path[, comments, ...])</code>	Write graph G in single-line adjacency-list format to path.
<code>parse_adjlist(lines[, comments, delimiter, ...])</code>	Parse lines of a graph adjacency list representation.
<code>generate_adjlist(G[, delimiter])</code>	Generate a single line of the graph G in adjacency list format.

9.1.2 read_adjlist

read_adjlist (*path*, *comments*='#', *delimiter*=None, *create_using*=None, *nodetype*=None, *encoding*='utf-8')

Read graph in adjacency list format from path.

Parameters

- **path** (*string or file*) – Filename or file handle to read. Filenames ending in .gz or .bz2 will be uncompressed.
- **create_using** (*NetworkX graph container*) – Use given NetworkX graph for holding nodes or edges.
- **nodetype** (*Python type, optional*) – Convert nodes to this type.

- **comments** (*string, optional*) – Marker for comment lines
- **delimiter** (*string, optional*) – Separator for node labels. The default is whitespace.
- **create_using** – Use given NetworkX graph for holding nodes or edges.

Returns **G** – The graph corresponding to the lines in adjacency list format.

Return type NetworkX graph

Examples

```
>>> G=nx.path_graph(4)
>>> nx.write_adjlist(G, "test.adjlist")
>>> G=nx.read_adjlist("test.adjlist")
```

The path can be a filehandle or a string with the name of the file. If a filehandle is provided, it has to be opened in ‘rb’ mode.

```
>>> fh=open("test.adjlist", 'rb')
>>> G=nx.read_adjlist(fh)
```

Filenames ending in .gz or .bz2 will be compressed.

```
>>> nx.write_adjlist(G, "test.adjlist.gz")
>>> G=nx.read_adjlist("test.adjlist.gz")
```

The optional nodetype is a function to convert node strings to nodetype.

For example

```
>>> G=nx.read_adjlist("test.adjlist", nodetype=int)
```

will attempt to convert all nodes to integer type.

Since nodes must be hashable, the function nodetype must return hashable types (e.g. int, float, str, frozenset - or tuples of those, etc.)

The optional create_using parameter is a NetworkX graph container. The default is Graph(), an undirected graph. To read the data as a directed graph use

```
>>> G=nx.read_adjlist("test.adjlist", create_using=nx.DiGraph())
```

Notes

This format does not store graph or node data.

See also:

`write_adjlist()`

9.1.3 write_adjlist

write_adjlist (*G, path, comments='#', delimiter=' ', encoding='utf-8'*)

Write graph G in single-line adjacency-list format to path.

Parameters

- **G** (*NetworkX graph*) –

- **path** (*string or file*) – Filename or file handle for data output. Filenames ending in .gz or .bz2 will be compressed.
- **comments** (*string, optional*) – Marker for comment lines
- **delimiter** (*string, optional*) – Separator for node labels
- **encoding** (*string, optional*) – Text encoding.

Examples

```
>>> G=nx.path_graph(4)
>>> nx.write_adjlist(G, "test.adjlist")
```

The path can be a filehandle or a string with the name of the file. If a filehandle is provided, it has to be opened in 'wb' mode.

```
>>> fh=open("test.adjlist", 'wb')
>>> nx.write_adjlist(G, fh)
```

Notes

This format does not store graph, node, or edge data.

See also:

`read_adjlist()`, `generate_adjlist()`

9.1.4 parse_adjlist

parse_adjlist (*lines*, *comments='#'*, *delimiter=None*, *create_using=None*, *nodetype=None*)

Parse lines of a graph adjacency list representation.

Parameters

- **lines** (*list or iterator of strings*) – Input data in adjlist format
- **create_using** (*NetworkX graph container*) – Use given NetworkX graph for holding nodes or edges.
- **nodetype** (*Python type, optional*) – Convert nodes to this type.
- **comments** (*string, optional*) – Marker for comment lines
- **delimiter** (*string, optional*) – Separator for node labels. The default is whitespace.
- **create_using** – Use given NetworkX graph for holding nodes or edges.

Returns **G** – The graph corresponding to the lines in adjacency list format.

Return type NetworkX graph

Examples

```
>>> lines = ['1 2 5',
...          '2 3 4',
...          '3 5',
...          '4',
...          '5']
>>> G = nx.parse_adjlist(lines, nodetype = int)
>>> G.nodes()
[1, 2, 3, 4, 5]
>>> G.edges()
[(1, 2), (1, 5), (2, 3), (2, 4), (3, 5)]
```

See also:

`read_adjlist()`

9.1.5 generate_adjlist

generate_adjlist (*G*, *delimiter*=' ')

Generate a single line of the graph *G* in adjacency list format.

Parameters

- **G** (*NetworkX graph*) –
- **delimiter** (*string, optional*) – Separator for node labels

Returns **lines** – Lines of data in adjlist format.

Return type `string`

Examples

```
>>> G = nx.lollipop_graph(4, 3)
>>> for line in nx.generate_adjlist(G):
...     print(line)
0 1 2 3
1 2 3
2 3
3 4
4 5
5 6
6
```

See also:

`write_adjlist()`, `read_adjlist()`

9.2 Multiline Adjacency List

9.2.1 Multi-line Adjacency List

Read and write NetworkX graphs as multi-line adjacency lists.

The multi-line adjacency list format is useful for graphs with nodes that can be meaningfully represented as strings. With this format simple edge data can be stored but node or graph data is not.

Format

The first label in a line is the source node label followed by the node degree d . The next d lines are target node labels and optional edge data. That pattern repeats for all nodes in the graph.

The graph with edges a-b, a-c, d-e can be represented as the following adjacency list (anything following the # in a line is a comment):

```
# example.multiline-adjlist
a 2
b
c
d 1
e
```

<code>read_multiline_adjlist(path[, comments, ...])</code>	Read graph in multi-line adjacency list format from path.
<code>write_multiline_adjlist(G, path[, ...])</code>	Write the graph G in multiline adjacency list format to path
<code>parse_multiline_adjlist(lines[, comments, ...])</code>	Parse lines of a multiline adjacency list representation of a graph.
<code>generate_multiline_adjlist(G[, delimiter])</code>	Generate a single line of the graph G in multiline adjacency list format.

9.2.2 read_multiline_adjlist

read_multiline_adjlist (*path*, *comments*='#', *delimiter*=None, *create_using*=None, *nodetype*=None, *edgetype*=None, *encoding*='utf-8')

Read graph in multi-line adjacency list format from path.

Parameters

- **path** (*string or file*) – Filename or file handle to read. Filenames ending in .gz or .bz2 will be uncompressed.
- **create_using** (*NetworkX graph container*) – Use given NetworkX graph for holding nodes or edges.
- **nodetype** (*Python type, optional*) – Convert nodes to this type.
- **edgetype** (*Python type, optional*) – Convert edge data to this type.
- **comments** (*string, optional*) – Marker for comment lines
- **delimiter** (*string, optional*) – Separator for node labels. The default is whitespace.
- **create_using** – Use given NetworkX graph for holding nodes or edges.

Returns G

Return type NetworkX graph

Examples

```
>>> G=nx.path_graph(4)
>>> nx.write_multiline_adjlist(G,"test.adjlist")
>>> G=nx.read_multiline_adjlist("test.adjlist")
```

The path can be a file or a string with the name of the file. If a file is provided, it has to be opened in 'rb' mode.

```
>>> fh=open("test.adjlist", 'rb')
>>> G=nx.read_multiline_adjlist(fh)
```

Filenames ending in .gz or .bz2 will be compressed.

```
>>> nx.write_multiline_adjlist(G, "test.adjlist.gz")
>>> G=nx.read_multiline_adjlist("test.adjlist.gz")
```

The optional `nodetype` is a function to convert node strings to `nodetype`.

For example

```
>>> G=nx.read_multiline_adjlist("test.adjlist", nodetype=int)
```

will attempt to convert all nodes to integer type.

The optional `edgetype` is a function to convert edge data strings to `edgetype`.

```
>>> G=nx.read_multiline_adjlist("test.adjlist")
```

The optional `create_using` parameter is a NetworkX graph container. The default is `Graph()`, an undirected graph. To read the data as a directed graph use

```
>>> G=nx.read_multiline_adjlist("test.adjlist", create_using=nx.DiGraph())
```

Notes

This format does not store graph, node, or edge data.

See also:

`write_multiline_adjlist()`

9.2.3 write_multiline_adjlist

write_multiline_adjlist (*G*, *path*, *delimiter*=' ', *comments*='#', *encoding*='utf-8')

Write the graph *G* in multiline adjacency list format to *path*

Parameters

- **G** (*NetworkX graph*) –
- **comments** (*string, optional*) – Marker for comment lines
- **delimiter** (*string, optional*) – Separator for node labels
- **encoding** (*string, optional*) – Text encoding.

Examples

```
>>> G=nx.path_graph(4)
>>> nx.write_multiline_adjlist(G, "test.adjlist")
```

The *path* can be a file handle or a string with the name of the file. If a file handle is provided, it has to be opened in 'wb' mode.

```
>>> fh=open("test.adjlist", 'wb')
>>> nx.write_multiline_adjlist(G, fh)
```

Filenames ending in .gz or .bz2 will be compressed.

```
>>> nx.write_multiline_adjlist(G, "test.adjlist.gz")
```

See also:

```
read_multiline_adjlist()
```

9.2.4 parse_multiline_adjlist

parse_multiline_adjlist(*lines*, *comments*='#', *delimiter*=None, *create_using*=None, *node-type*=None, *edgetype*=None)

Parse lines of a multiline adjacency list representation of a graph.

Parameters

- **lines** (*list or iterator of strings*) – Input data in multiline adjlist format
- **create_using** (*NetworkX graph container*) – Use given NetworkX graph for holding nodes or edges.
- **nodetype** (*Python type, optional*) – Convert nodes to this type.
- **comments** (*string, optional*) – Marker for comment lines
- **delimiter** (*string, optional*) – Separator for node labels. The default is whitespace.
- **create_using** – Use given NetworkX graph for holding nodes or edges.

Returns **G** – The graph corresponding to the lines in multiline adjacency list format.

Return type NetworkX graph

Examples

```
>>> lines = ['1 2',
...         "2 {'weight':3, 'name': 'Frodo'}",
...         "3 {}",
...         "2 1",
...         "5 {'weight':6, 'name': 'Saruman'}"]
>>> G = nx.parse_multiline_adjlist(iter(lines), nodetype = int)
>>> G.nodes()
[1, 2, 3, 5]
```

9.2.5 generate_multiline_adjlist

generate_multiline_adjlist(*G*, *delimiter*=' ')

Generate a single line of the graph *G* in multiline adjacency list format.

Parameters

- **G** (*NetworkX graph*) –
- **delimiter** (*string, optional*) – Separator for node labels

Returns **lines** – Lines of data in multiline adjlist format.

Return type *string*

Examples

```
>>> G = nx.lollipop_graph(4, 3)
>>> for line in nx.generate_multiline_adjlist(G):
...     print(line)
0 3
1 {}
2 {}
3 {}
1 2
2 {}
3 {}
2 1
3 {}
3 1
4 {}
4 1
5 {}
5 1
6 {}
6 0
```

See also:

`write_multiline_adjlist()`, `read_multiline_adjlist()`

9.3 Edge List

9.3.1 Edge Lists

Read and write NetworkX graphs as edge lists.

The multi-line adjacency list format is useful for graphs with nodes that can be meaningfully represented as strings. With the edgelist format simple edge data can be stored but node or graph data is not. There is no way of representing isolated nodes unless the node has a self-loop edge.

Format

You can read or write three formats of edge lists with these functions.

Node pairs with no data:

```
1 2
```

Python dictionary as data:

```
1 2 {'weight':7, 'color':'green'}
```

Arbitrary data:

```
1 2 7 green
```

`read_edgelist(path[, comments, delimiter, ...])`

Read a graph from a list of edges.

`write_edgelist(G, path[, comments, ...])`

Write graph as a list of edges.

Continued on next page

Table 9.3 – continued from previous page

<code>read_weighted_edgelist(path[, comments, ...])</code>	Read a graph as list of edges with numeric weights.
<code>write_weighted_edgelist(G, path[, comments, ...])</code>	Write graph G as a list of edges with numeric weights.
<code>generate_edgelist(G[, delimiter, data])</code>	Generate a single line of the graph G in edge list format.
<code>parse_edgelist(lines[, comments, delimiter, ...])</code>	Parse lines of an edge list representation of a graph.

9.3.2 read_edgelist

read_edgelist (*path*, *comments*='#', *delimiter*=None, *create_using*=None, *nodetype*=None, *data*=True, *edgetype*=None, *encoding*='utf-8')

Read a graph from a list of edges.

Parameters

- **path** (*file or string*) – File or filename to read. If a file is provided, it must be opened in 'rb' mode. Filenames ending in .gz or .bz2 will be uncompressed.
- **comments** (*string, optional*) – The character used to indicate the start of a comment.
- **delimiter** (*string, optional*) – The string used to separate values. The default is whitespace.
- **create_using** (*Graph container, optional*) – Use specified container to build graph. The default is networkx.Graph, an undirected graph.
- **nodetype** (*int, float, str, Python type, optional*) – Convert node data from strings to specified type
- **data** (*bool or list of (label,type) tuples*) – Tuples specifying dictionary key names and types for edge data
- **edgetype** (*int, float, str, Python type, optional OBSOLETE*) – Convert edge data from strings to specified type and use as 'weight'
- **encoding** (*string, optional*) – Specify which encoding to use when reading file.

Returns **G** – A networkx Graph or other type specified with create_using

Return type graph

Examples

```
>>> nx.write_edgelist(nx.path_graph(4), "test.edgelist")
>>> G=nx.read_edgelist("test.edgelist")
```

```
>>> fh=open("test.edgelist", 'rb')
>>> G=nx.read_edgelist(fh)
>>> fh.close()
```

```
>>> G=nx.read_edgelist("test.edgelist", nodetype=int)
>>> G=nx.read_edgelist("test.edgelist", create_using=nx.DiGraph())
```

Edgelist with data in a list:

```
>>> textline = '1 2 3'
>>> fh = open('test.edgelist', 'w')
>>> d = fh.write(textline)
>>> fh.close()
>>> G = nx.read_edgelist('test.edgelist', nodetype=int, data= (('weight', float),))
```

```
>>> G.nodes()
[1, 2]
>>> G.edges(data=True)
[(1, 2, {'weight': 3.0})]
```

See `parse_edgelist()` for more examples of formatting.

See also:

`parse_edgelist()`

Notes

Since nodes must be hashable, the function `nodetype` must return hashable types (e.g. `int`, `float`, `str`, `frozenset` - or tuples of those, etc.)

9.3.3 write_edgelist

write_edgelist (*G*, *path*, *comments*='#', *delimiter*=' ', *data*=True, *encoding*='utf-8')

Write graph as a list of edges.

Parameters

- **G** (*graph*) – A NetworkX graph
- **path** (*file or string*) – File or filename to write. If a file is provided, it must be opened in 'wb' mode. Filenames ending in `.gz` or `.bz2` will be compressed.
- **comments** (*string, optional*) – The character used to indicate the start of a comment
- **delimiter** (*string, optional*) – The string used to separate values. The default is whitespace.
- **data** (*bool or list, optional*) – If False write no edge data. If True write a string representation of the edge data dictionary.. If a list (or other iterable) is provided, write the keys specified in the list.
- **encoding** (*string, optional*) – Specify which encoding to use when writing file.

Examples

```
>>> G=nx.path_graph(4)
>>> nx.write_edgelist(G, "test.edgelist")
>>> G=nx.path_graph(4)
>>> fh=open("test.edgelist", 'wb')
>>> nx.write_edgelist(G, fh)
>>> nx.write_edgelist(G, "test.edgelist.gz")
>>> nx.write_edgelist(G, "test.edgelist.gz", data=False)
```

```
>>> G=nx.Graph()
>>> G.add_edge(1,2,weight=7,color='red')
>>> nx.write_edgelist(G,'test.edgelist',data=False)
>>> nx.write_edgelist(G,'test.edgelist',data=['color'])
>>> nx.write_edgelist(G,'test.edgelist',data=['color','weight'])
```

See also:

`write_edgelist()`, `write_weighted_edgelist()`

9.3.4 read_weighted_edgelist

read_weighted_edgelist (*path*, *comments*='#', *delimiter*=None, *create_using*=None, *nodetype*=None, *encoding*='utf-8')

Read a graph as list of edges with numeric weights.

Parameters

- **path** (*file or string*) – File or filename to read. If a file is provided, it must be opened in 'rb' mode. Filenames ending in .gz or .bz2 will be uncompressed.
- **comments** (*string, optional*) – The character used to indicate the start of a comment.
- **delimiter** (*string, optional*) – The string used to separate values. The default is whitespace.
- **create_using** (*Graph container, optional*) – Use specified container to build graph. The default is networkx.Graph, an undirected graph.
- **nodetype** (*int, float, str, Python type, optional*) – Convert node data from strings to specified type
- **encoding** (*string, optional*) – Specify which encoding to use when reading file.

Returns **G** – A networkx Graph or other type specified with create_using

Return type graph

Notes

Since nodes must be hashable, the function nodetype must return hashable types (e.g. int, float, str, frozenset - or tuples of those, etc.)

Example edgelist file format.

With numeric edge data:

```
# read with
# >>> G=nx.read_weighted_edgelist(fh)
# source target data
a b 1
a c 3.14159
d e 42
```

9.3.5 write_weighted_edgelist

write_weighted_edgelist (*G*, *path*, *comments*='#', *delimiter*=' ', *encoding*='utf-8')

Write graph G as a list of edges with numeric weights.

Parameters

- **G** (*graph*) – A NetworkX graph
- **path** (*file or string*) – File or filename to write. If a file is provided, it must be opened in 'wb' mode. Filenames ending in .gz or .bz2 will be compressed.
- **comments** (*string, optional*) – The character used to indicate the start of a comment
- **delimiter** (*string, optional*) – The string used to separate values. The default is whitespace.

- **encoding** (*string, optional*) – Specify which encoding to use when writing file.

Examples

```
>>> G=nx.Graph()
>>> G.add_edge(1,2,weight=7)
>>> nx.write_weighted_edgelist(G, 'test.weighted.edgelist')
```

See also:

`read_edgelist()`, `write_edgelist()`, `write_weighted_edgelist()`

9.3.6 generate_edgelist

generate_edgelist (*G, delimiter=' ', data=True*)

Generate a single line of the graph *G* in edge list format.

Parameters

- **G** (*NetworkX graph*) –
- **delimiter** (*string, optional*) – Separator for node labels
- **data** (*bool or list of keys*) – If False generate no edge data. If True use a dictionary representation of edge data. If a list of keys use a list of data values corresponding to the keys.

Returns *lines* – Lines of data in adjlist format.

Return type *string*

Examples

```
>>> G = nx.lollipop_graph(4, 3)
>>> G[1][2]['weight'] = 3
>>> G[3][4]['capacity'] = 12
>>> for line in nx.generate_edgelist(G, data=False):
...     print(line)
0 1
0 2
0 3
1 2
1 3
2 3
3 4
4 5
5 6
```

```
>>> for line in nx.generate_edgelist(G):
...     print(line)
0 1 {}
0 2 {}
0 3 {}
1 2 {'weight': 3}
1 3 {}
2 3 {}
3 4 {'capacity': 12}
```

```
4 5 {}
5 6 {}
```

```
>>> for line in nx.generate_edgelist(G, data=['weight']):
...     print(line)
0 1
0 2
0 3
1 2 3
1 3
2 3
3 4
4 5
5 6
```

See also:

`write_adjlist()`, `read_adjlist()`

9.3.7 parse_edgelist

parse_edgelist (*lines*, *comments='#'*, *delimiter=None*, *create_using=None*, *nodetype=None*, *data=True*)

Parse lines of an edge list representation of a graph.

Parameters

- **lines** (*list or iterator of strings*) – Input data in edgelist format
- **comments** (*string, optional*) – Marker for comment lines
- **delimiter** (*string, optional*) – Separator for node labels
- **create_using** (*NetworkX graph container, optional*) – Use given NetworkX graph for holding nodes or edges.
- **nodetype** (*Python type, optional*) – Convert nodes to this type.
- **data** (*bool or list of (label,type) tuples*) – If False generate no edge data or if True use a dictionary representation of edge data or a list tuples specifying dictionary key names and types for edge data.

Returns **G** – The graph corresponding to lines

Return type NetworkX Graph

Examples

Edgelist with no data:

```
>>> lines = ["1 2",
...         "2 3",
...         "3 4"]
>>> G = nx.parse_edgelist(lines, nodetype = int)
>>> G.nodes()
[1, 2, 3, 4]
>>> G.edges()
[(1, 2), (2, 3), (3, 4)]
```

Edgelist with data in Python dictionary representation:

```
>>> lines = ["1 2 {'weight':3}",
...          "2 3 {'weight':27}",
...          "3 4 {'weight':3.0}"]
>>> G = nx.parse_edgelist(lines, nodetype = int)
>>> G.nodes()
[1, 2, 3, 4]
>>> G.edges(data = True)
[(1, 2, {'weight': 3}), (2, 3, {'weight': 27}), (3, 4, {'weight': 3.0})]
```

Edgelist with data in a list:

```
>>> lines = ["1 2 3",
...          "2 3 27",
...          "3 4 3.0"]
>>> G = nx.parse_edgelist(lines, nodetype = int, data=({'weight',float},))
>>> G.nodes()
[1, 2, 3, 4]
>>> G.edges(data = True)
[(1, 2, {'weight': 3.0}), (2, 3, {'weight': 27.0}), (3, 4, {'weight': 3.0})]
```

See also:

`read_weighted_edgelist()`

9.4 GEXF

9.4.1 GEXF

Read and write graphs in GEXF format.

GEXF (Graph Exchange XML Format) is a language for describing complex network structures, their associated data and dynamics.

This implementation does not support mixed graphs (directed and undirected edges together).

Format

GEXF is an XML format. See <http://gexf.net/format/schema.html> for the specification and <http://gexf.net/format/basic.html> for examples.

<code>read_gexf(path[, node_type, relabel, version])</code>	Read graph in GEXF format from path.
<code>write_gexf(G, path[, encoding, prettyprint, ...])</code>	Write G in GEXF format to path.
<code>relabel_gexf_graph(G)</code>	Relabel graph using “label” node keyword for node label.

9.4.2 read_gexf

read_gexf (*path*, *node_type=None*, *relabel=False*, *version='1.1draft'*)

Read graph in GEXF format from path.

“GEXF (Graph Exchange XML Format) is a language for describing complex networks structures, their associated data and dynamics”¹.

¹ GEXF graph format, <http://gexf.net/format/>

Parameters

- **path** (*file or string*) – File or file name to write. File names ending in .gz or .bz2 will be compressed.
- **node_type** (*Python type (default: None)*) – Convert node ids to this type if not None.
- **relabel** (*bool (default: False)*) – If True relabel the nodes to use the GEXF node “label” attribute instead of the node “id” attribute as the NetworkX node label.

Returns graph – If no parallel edges are found a Graph or DiGraph is returned. Otherwise a Multi-Graph or MultiDiGraph is returned.

Return type NetworkX graph

Notes

This implementation does not support mixed graphs (directed and undirected edges together).

References**9.4.3 write_gexf**

write_gexf (*G, path, encoding='utf-8', prettyprint=True, version='1.1draft'*)

Write G in GEXF format to path.

“GEXF (Graph Exchange XML Format) is a language for describing complex networks structures, their associated data and dynamics”².

Parameters

- **G** (*graph*) – A NetworkX graph
- **path** (*file or string*) – File or file name to write. File names ending in .gz or .bz2 will be compressed.
- **encoding** (*string (optional)*) – Encoding for text data.
- **prettyprint** (*bool (optional)*) – If True use line breaks and indenting in output XML.

Examples

```
>>> G=nx.path_graph(4)
>>> nx.write_gexf(G, "test.gexf")
```

Notes

This implementation does not support mixed graphs (directed and undirected edges together).

The node id attribute is set to be the string of the node label. If you want to specify an id use set it as node data, e.g. `node['a']['id']=1` to set the id of node ‘a’ to 1.

² GEXF graph format, <http://gexf.net/format/>

References

9.4.4 relabel_gexf_graph

relabel_gexf_graph (*G*)

Relabel graph using “label” node keyword for node label.

Parameters *G* (*graph*) – A NetworkX graph read from GEXF data

Returns *H* – A NetworkX graph with relabel nodes

Return type graph

Notes

This function relabels the nodes in a NetworkX graph with the “label” attribute. It also handles relabeling the specific GEXF node attributes “parents”, and “pid”.

9.5 GML

Read graphs in GML format.

“GML, the G>raph Modelling Language, is our proposal for a portable file format for graphs. GML’s key features are portability, simple syntax, extensibility and flexibility. A GML file consists of a hierarchical key-value lists. Graphs can be annotated with arbitrary data structures. The idea for a common file format was born at the GD’95; this proposal is the outcome of many discussions. GML is the standard file format in the Graphlet graph editor system. It has been overtaken and adapted by several other systems for drawing graphs.”

See <http://www.infosun.fim.uni-passau.de/Graphlet/GML/gml-tr.html>

9.5.1 Format

See <http://www.infosun.fim.uni-passau.de/Graphlet/GML/gml-tr.html> for format specification.

Example graphs in GML format: <http://www-personal.umich.edu/~mejn/netdata/>

<code>read_gml(path[, label, destringizer])</code>	Read graph in GML format from path.
<code>write_gml(G, path[, stringizer])</code>	Write a graph <i>G</i> in GML format to the file or file handle <i>path</i> .
<code>parse_gml(lines[, label, destringizer])</code>	Parse GML graph from a string or iterable.
<code>generate_gml(G[, stringizer])</code>	Generate a single entry of the graph <i>G</i> in GML format.
<code>literal_destringizer(rep)</code>	Convert a Python literal to the value it represents.
<code>literal_stringizer(value)</code>	Convert a value to a Python literal in GML representation.

9.5.2 read_gml

read_gml (*path*, *label*=’label’, *destringizer*=None)

Read graph in GML format from path.

Parameters

- **path** (*filename or filehandle*) – The filename or filehandle to read from.
- **label** (*string, optional*) – If not None, the parsed nodes will be renamed according to node

attributes indicated by `label`. Default value: `'label'`.

- **destringizer** (*callable, optional*) – A deststringizer that recovers values stored as strings in GML. If it cannot convert a string to a value, a `ValueError` is raised. Default value : `None`.

Returns `G` – The parsed graph.

Return type `NetworkX graph`

Raises `NetworkXError` – If the input cannot be parsed.

See also:

`write_gml()`, `parse_gml()`

Notes

The GML specification says that files should be ASCII encoded, with any extended ASCII characters (iso8859-1) appearing as HTML character entities.

References

GML specification: <http://www.infosun.fim.uni-passau.de/Graphlet/GML/gml-tr.html>

Examples

```
>>> G = nx.path_graph(4)
>>> nx.write_gml(G, 'test.gml')
>>> H = nx.read_gml('test.gml')
```

9.5.3 write_gml

write_gml (`G`, `path`, `stringizer=None`)

Write a graph `G` in GML format to the file or file handle `path`.

Parameters

- **G** (*NetworkX graph*) – The graph to be converted to GML.
- **path** (*filename or filehandle*) – The filename or filehandle to write. Files whose names end with `.gz` or `.bz2` will be compressed.
- **stringizer** (*callable, optional*) – A stringizer which converts non-int/non-float/non-dict values into strings. If it cannot convert a value into a string, it should raise a `ValueError` to indicate that. Default value: `None`.

Raises `NetworkXError` – If `stringizer` cannot convert a value into a string, or the value to convert is not a string while `stringizer` is `None`.

See also:

`read_gml()`, `generate_gml()`

Notes

Graph attributes named `'directed'`, `'multigraph'`, `'node'` or `'edge'`, node attributes named `'id'` or `'label'`, edge attributes named `'source'` or `'target'` (or `'key'` if `G` is a multigraph) are ignored because these attribute names are used to encode the graph structure.

```
>>> G = nx.path_graph(4)
>>> nx.write_gml(G, "test.gml")
```

Filenames ending in `.gz` or `.bz2` will be compressed.

```
>>> nx.write_gml(G, "test.gml.gz")
```

9.5.4 parse_gml

parse_gml (*lines*, *label*='label', *destringizer*=None)

Parse GML graph from a string or iterable.

Parameters

- **lines** (*string or iterable of strings*) – Data in GML format.
- **label** (*string, optional*) – If not None, the parsed nodes will be renamed according to node attributes indicated by `label`. Default value: `'label'`.
- **destringizer** (*callable, optional*) – A deststringizer that recovers values stored as strings in GML. If it cannot convert a string to a value, a `ValueError` is raised. Default value : None.

Returns `G` – The parsed graph.

Return type NetworkX graph

Raises `NetworkXError` – If the input cannot be parsed.

See also:

`write_gml()`, `read_gml()`

Notes

This stores nested GML attributes as dictionaries in the NetworkX graph, node, and edge attribute structures.

References

GML specification: <http://www.infosun.fim.uni-passau.de/Graphlet/GML/gml-tr.html>

9.5.5 generate_gml

generate_gml (*G*, *stringizer*=None)

Generate a single entry of the graph `G` in GML format.

Parameters

- **G** (*NetworkX graph*) – The graph to be converted to GML.

- **stringizer** (*callable, optional*) – A stringizer which converts non-int/float/dict values into strings. If it cannot convert a value into a string, it should raise a `ValueError` raised to indicate that. Default value: `None`.

Returns `lines` – Lines of GML data. Newlines are not appended.

Return type generator of strings

Raises `NetworkXError` – If `stringizer` cannot convert a value into a string, or the value to convert is not a string while `stringizer` is `None`.

Notes

Graph attributes named `'directed'`, `'multigraph'`, `'node'` or `'edge'`, node attributes named `'id'` or `'label'`, edge attributes named `'source'` or `'target'` (or `'key'` if `G` is a multigraph) are ignored because these attribute names are used to encode the graph structure.

9.5.6 literal_destringizer

literal_destringizer (*rep*)

Convert a Python literal to the value it represents.

Parameters `rep` (*string*) – A Python literal.

Returns `value` – The value of the Python literal.

Return type `object`

Raises `ValueError` – If `rep` is not a Python literal.

9.5.7 literal_stringizer

literal_stringizer (*value*)

Convert a value to a Python literal in GML representation.

Parameters `value` (*object*) – The value to be converted to GML representation.

Returns `rep` – A double-quoted Python literal representing value. Unprintable characters are replaced by XML character references.

Return type `string`

Raises `ValueError` – If `value` cannot be converted to GML.

Notes

`literal_stringizer` is largely the same as `repr` in terms of functionality but attempts prefix unicode and bytes literals with `u` and `b` to provide better interoperability of data generated by Python 2 and Python 3.

The original value can be recovered using the `networkx.readwrite.gml.literal_destringizer` function.

9.6 Pickle

9.6.1 Pickled Graphs

Read and write NetworkX graphs as Python pickles.

“The pickle module implements a fundamental, but powerful algorithm for serializing and de-serializing a Python object structure. “Pickling” is the process whereby a Python object hierarchy is converted into a byte stream, and “unpickling” is the inverse operation, whereby a byte stream is converted back into an object hierarchy.”

Note that NetworkX graphs can contain any hashable Python object as node (not just integers and strings). For arbitrary data types it may be difficult to represent the data as text. In that case using Python pickles to store the graph data can be used.

Format

See <http://docs.python.org/library/pickle.html>

<code>read_gpickle(path)</code>	Read graph object in Python pickle format.
<code>write_gpickle(G, path[, protocol])</code>	Write graph in Python pickle format.

9.6.2 read_gpickle

read_gpickle (*path*)

Read graph object in Python pickle format.

Pickles are a serialized byte stream of a Python object³. This format will preserve Python objects used as nodes or edges.

Parameters *path* (*file or string*) – File or filename to write. Filenames ending in .gz or .bz2 will be uncompressed.

Returns *G* – A NetworkX graph

Return type graph

Examples

```
>>> G = nx.path_graph(4)
>>> nx.write_gpickle(G, "test.pickle")
>>> G = nx.read_gpickle("test.pickle")
```

References

9.6.3 write_gpickle

write_gpickle (*G, path, protocol=2*)

Write graph in Python pickle format.

³ <http://docs.python.org/library/pickle.html>

Pickles are a serialized byte stream of a Python object ⁴. This format will preserve Python objects used as nodes or edges.

Parameters

- **G** (*graph*) – A NetworkX graph
- **path** (*file or string*) – File or filename to write. Filenames ending in .gz or .bz2 will be compressed.
- **protocol** (*integer*) – Pickling protocol to use. Default value: `pickle.HIGHEST_PROTOCOL`.

Examples

```
>>> G = nx.path_graph(4)
>>> nx.write_gpickle(G, "test.gpickle")
```

References

9.7 GraphML

9.7.1 GraphML

Read and write graphs in GraphML format.

This implementation does not support mixed graphs (directed and undirected edges together), hyperedges, nested graphs, or ports.

“GraphML is a comprehensive and easy-to-use file format for graphs. It consists of a language core to describe the structural properties of a graph and a flexible extension mechanism to add application-specific data. Its main features include support of

- directed, undirected, and mixed graphs,
- hypergraphs,
- hierarchical graphs,
- graphical representations,
- references to external data,
- application-specific attribute data, and
- light-weight parsers.

Unlike many other file formats for graphs, GraphML does not use a custom syntax. Instead, it is based on XML and hence ideally suited as a common denominator for all kinds of services generating, archiving, or processing graphs.”

<http://graphml.graphdrawing.org/>

⁴ <http://docs.python.org/library/pickle.html>

Format

GraphML is an XML format. See <http://graphml.graphdrawing.org/specification.html> for the specification and <http://graphml.graphdrawing.org/primer/graphml-primer.html> for examples.

<code>read_graphml(path[, node_type])</code>	Read graph in GraphML format from path.
<code>write_graphml(G, path[, encoding, prettyprint])</code>	Write G in GraphML XML format to path

9.7.2 read_graphml

read_graphml (*path*, *node_type*=<type 'str'>)

Read graph in GraphML format from path.

Parameters

- **path** (*file or string*) – File or filename to write. Filenames ending in .gz or .bz2 will be compressed.
- **node_type** (*Python type (default: str)*) – Convert node ids to this type

Returns **graph** – If no parallel edges are found a Graph or DiGraph is returned. Otherwise a Multi-Graph or MultiDiGraph is returned.

Return type NetworkX graph

Notes

This implementation does not support mixed graphs (directed and undirected edges together), hypergraphs, nested graphs, or ports.

For multigraphs the GraphML edge “id” will be used as the edge key. If not specified then they “key” attribute will be used. If there is no “key” attribute a default NetworkX multigraph edge key will be provided.

Files with the yEd “yfiles” extension will can be read but the graphics information is discarded.

yEd compressed files (“file.graphmlz” extension) can be read by renaming the file to “file.graphml.gz”.

9.7.3 write_graphml

write_graphml (*G*, *path*, *encoding*=‘utf-8’, *prettyprint*=True)

Write G in GraphML XML format to path

Parameters

- **G** (*graph*) – A networkx graph
- **path** (*file or string*) – File or filename to write. Filenames ending in .gz or .bz2 will be compressed.
- **encoding** (*string (optional)*) – Encoding for text data.
- **prettyprint** (*bool (optional)*) – If True use line breaks and indenting in output XML.

Examples

```
>>> G=nx.path_graph(4)
>>> nx.write_graphml(G, "test.graphml")
```

Notes

This implementation does not support mixed graphs (directed and undirected edges together) hyperedges, nested graphs, or ports.

9.8 JSON

9.8.1 JSON data

Generate and parse JSON serializable data for NetworkX graphs.

These formats are suitable for use with the d3.js examples <http://d3js.org/>

The three formats that you can generate with NetworkX are:

- node-link like in the d3.js example <http://bl.ocks.org/mbostock/4062045>
 - tree like in the d3.js example <http://bl.ocks.org/mbostock/4063550>
 - adjacency like in the d3.js example <http://bost.ocks.org/mike/miserables/>
-

9.9 LEDA

Read graphs in LEDA format.

LEDA is a C++ class library for efficient data types and algorithms.

9.9.1 Format

See http://www.algorithmic-solutions.info/leda_guide/graphs/leda_native_graph_fileformat.html

<code>read_leda(path[, encoding])</code>	Read graph in LEDA format from path.
<code>parse_leda(lines)</code>	Read graph in LEDA format from string or iterable.

9.9.2 read_leda

read_leda (*path*, *encoding*='UTF-8')

Read graph in LEDA format from path.

Parameters **path** (*file or string*) – File or filename to read. Filenames ending in .gz or .bz2 will be uncompressed.

Returns **G**

Return type NetworkX graph

Examples

```
G=nx.read_leda('file.leda')
```


References

9.9.3 parse_leda

parse_leda (*lines*)

Read graph in LEDA format from string or iterable.

Parameters **lines** (*string or iterable*) – Data in LEDA format.

Returns **G**

Return type NetworkX graph

Examples

```
G=nx.parse_leda(string)
```

References

9.10 YAML

9.10.1 YAML

Read and write NetworkX graphs in YAML format.

“YAML is a data serialization format designed for human readability and interaction with scripting languages.” See <http://www.yaml.org> for documentation.

Format

<http://pyyaml.org/wiki/PyYAML>

<code>read_yaml(path)</code>	Read graph in YAML format from path.
<code>write_yaml(G, path[, encoding])</code>	Write graph G in YAML format to path.

9.10.2 read_yaml

read_yaml (*path*)

Read graph in YAML format from path.

YAML is a data serialization format designed for human readability and interaction with scripting languages ⁵.

Parameters **path** (*file or string*) – File or filename to read. Filenames ending in .gz or .bz2 will be uncompressed.

Returns **G**

Return type NetworkX graph

⁵ <http://www.yaml.org>

Examples

```
>>> G=nx.path_graph(4)
>>> nx.write_yaml(G, 'test.yaml')
>>> G=nx.read_yaml('test.yaml')
```

References

9.10.3 write_yaml

write_yaml (*G*, *path*, *encoding*='UTF-8', ***kws*)

Write graph *G* in YAML format to *path*.

YAML is a data serialization format designed for human readability and interaction with scripting languages ⁶.

Parameters

- **G** (*graph*) – A NetworkX graph
- **path** (*file or string*) – File or filename to write. Filenames ending in .gz or .bz2 will be compressed.
- **encoding** (*string, optional*) – Specify which encoding to use when writing file.

Examples

```
>>> G=nx.path_graph(4)
>>> nx.write_yaml(G, 'test.yaml')
```

References

9.11 SparseGraph6

9.11.1 Graph6

Graph6

Read and write graphs in graph6 format.

Format

“graph6 and sparse6 are formats for storing undirected graphs in a compact manner, using only printable ASCII characters. Files in these formats have text type and contain one line per graph.”

See <http://cs.anu.edu.au/~bdm/data/formats.txt> for details.

<code>parse_graph6(string)</code>	Read a simple undirected graph in graph6 format from string.
<code>read_graph6(path)</code>	Read simple undirected graphs in graph6 format from path.
<code>generate_graph6(G[, nodes, header])</code>	Generate graph6 format string from a simple undirected graph.
<code>write_graph6(G, path[, nodes, header])</code>	Write a simple undirected graph to path in graph6 format.

⁶ <http://www.yaml.org>

parse_graph6

parse_graph6 (*string*)

Read a simple undirected graph in graph6 format from string.

Parameters **string** (*string*) – Data in graph6 format

Returns **G**

Return type *Graph*

Raises *NetworkXError* – If the string is unable to be parsed in graph6 format

Examples

```
>>> G = nx.parse_graph6('A_')
>>> sorted(G.edges())
[(0, 1)]
```

See also:

generate_graph6(), *read_graph6()*, *write_graph6()*

References

Graph6 specification: <http://cs.anu.edu.au/~bdm/data/formats.txt> for details.

read_graph6

read_graph6 (*path*)

Read simple undirected graphs in graph6 format from path.

Parameters **path** (*file or string*) – File or filename to write.

Returns **G** – If the file contains multiple lines then a list of graphs is returned

Return type *Graph* or list of *Graphs*

Raises *NetworkXError* – If the string is unable to be parsed in graph6 format

Examples

```
>>> nx.write_graph6(nx.Graph([(0,1)]), 'test.g6')
>>> G = nx.read_graph6('test.g6')
>>> sorted(G.edges())
[(0, 1)]
```

See also:

generate_graph6(), *parse_graph6()*, *write_graph6()*

References

Graph6 specification: <http://cs.anu.edu.au/~bdm/data/formats.txt> for details.

generate_graph6

generate_graph6 (*G*, *nodes=None*, *header=True*)

Generate graph6 format string from a simple undirected graph.

Parameters

- **G** (*Graph (undirected)*) –
- **nodes** (*list or iterable*) – Nodes are labeled 0...n-1 in the order provided. If None the ordering given by `G.nodes()` is used.
- **header** (*bool*) – If True add '>>graph6<<' string to head of data

Returns *s* – String in graph6 format

Return type `string`

Raises `NetworkXError` – If the graph is directed or has parallel edges

Examples

```
>>> G = nx.Graph([(0, 1)])
>>> nx.generate_graph6(G)
'>>graph6<<A_'
```

See also:

`read_graph6()`, `parse_graph6()`, `write_graph6()`

Notes

The format does not support edge or node labels, parallel edges or self loops. If self loops are present they are silently ignored.

References

Graph6 specification: <http://cs.anu.edu.au/~bdm/data/formats.txt> for details.

write_graph6

write_graph6 (*G*, *path*, *nodes=None*, *header=True*)

Write a simple undirected graph to path in graph6 format.

Parameters

- **G** (*Graph (undirected)*) –
- **path** (*file or string*) – File or filename to write.
- **nodes** (*list or iterable*) – Nodes are labeled 0...n-1 in the order provided. If None the ordering given by `G.nodes()` is used.
- **header** (*bool*) – If True add '>>graph6<<' string to head of data

Raises `NetworkXError` – If the graph is directed or has parallel edges

Examples

```
>>> G = nx.Graph([(0, 1)])
>>> nx.write_graph6(G, 'test.g6')
```

See also:

`generate_graph6()`, `parse_graph6()`, `read_graph6()`

Notes

The format does not support edge or node labels, parallel edges or self loops. If self loops are present they are silently ignored.

References

Graph6 specification: <http://cs.anu.edu.au/~bdm/data/formats.txt> for details.

9.11.2 Sparse6

Sparse6

Read and write graphs in sparse6 format.

Format

“graph6 and sparse6 are formats for storing undirected graphs in a compact manner, using only printable ASCII characters. Files in these formats have text type and contain one line per graph.”

See <http://cs.anu.edu.au/~bdm/data/formats.txt> for details.

<code>parse_sparse6(string)</code>	Read an undirected graph in sparse6 format from string.
<code>read_sparse6(path)</code>	Read an undirected graph in sparse6 format from path.
<code>generate_sparse6(G[, nodes, header])</code>	Generate sparse6 format string from an undirected graph.
<code>write_sparse6(G, path[, nodes, header])</code>	Write graph G to given path in sparse6 format.

parse_sparse6

parse_sparse6 (*string*)

Read an undirected graph in sparse6 format from string.

Parameters **string** (*string*) – Data in sparse6 format

Returns **G**

Return type *Graph*

Raises `NetworkXError` – If the string is unable to be parsed in sparse6 format

Examples

```
>>> G = nx.parse_sparse6(':A_')
>>> sorted(G.edges())
[(0, 1), (0, 1), (0, 1)]
```

See also:

`generate_sparse6()`, `read_sparse6()`, `write_sparse6()`

References

Sparse6 specification: <http://cs.anu.edu.au/~bdm/data/formats.txt>

read_sparse6

read_sparse6(*path*)

Read an undirected graph in sparse6 format from path.

Parameters *path* (*file or string*) – File or filename to write.

Returns *G* – If the file contains multiple lines then a list of graphs is returned

Return type Graph/Multigraph or list of Graphs/MultiGraphs

Raises `NetworkXError` – If the string is unable to be parsed in sparse6 format

Examples

```
>>> nx.write_sparse6(nx.Graph([(0,1), (0,1), (0,1)]), 'test.s6')
>>> G = nx.read_sparse6('test.s6')
>>> sorted(G.edges())
[(0, 1)]
```

See also:

`generate_sparse6()`, `read_sparse6()`, `parse_sparse6()`

References

Sparse6 specification: <http://cs.anu.edu.au/~bdm/data/formats.txt>

generate_sparse6

generate_sparse6(*G*, *nodes=None*, *header=True*)

Generate sparse6 format string from an undirected graph.

Parameters

- *G* (*Graph (undirected)*) –
- **nodes** (*list or iterable*) – Nodes are labeled 0...n-1 in the order provided. If None the ordering given by `G.nodes()` is used.
- **header** (*bool*) – If True add '>>sparse6<<' string to head of data

Returns *s* – String in sparse6 format

Return type `string`

Raises `NetworkXError` – If the graph is directed

Examples

```
>>> G = nx.MultiGraph([(0, 1), (0, 1), (0, 1)])
>>> nx.generate_sparse6(G)
'>>sparse6<<:A_'
```

See also:

`read_sparse6()`, `parse_sparse6()`, `write_sparse6()`

Notes

The format does not support edge or node labels.

References

Sparse6 specification: <http://cs.anu.edu.au/~bdm/data/formats.txt> for details.

write_sparse6

write_sparse6(*G*, *path*, *nodes=None*, *header=True*)

Write graph *G* to given path in sparse6 format. :param *G*: :type *G*: Graph (undirected) :param *path*: File or filename to write

Parameters

- **nodes** (*list or iterable*) – Nodes are labeled 0...n-1 in the order provided. If *None* the ordering given by *G.nodes()* is used.
- **header** (*bool*) – If *True* add '>>sparse6<<' string to head of data

Raises `NetworkXError` – If the graph is directed

Examples

```
>>> G = nx.Graph([(0, 1), (0, 1), (0, 1)])
>>> nx.write_sparse6(G, 'test.s6')
```

See also:

`read_sparse6()`, `parse_sparse6()`, `generate_sparse6()`

Notes

The format does not support edge or node labels.

References

Sparse6 specification: <http://cs.anu.edu.au/~bdm/data/formats.txt> for details.

9.12 Pajek

9.12.1 Pajek

Read graphs in Pajek format.

This implementation handles directed and undirected graphs including those with self loops and parallel edges.

Format

See <http://vlado.fmf.uni-lj.si/pub/networks/pajek/doc/draweps.htm> for format information.

<code>read_pajek(path[, encoding])</code>	Read graph in Pajek format from path.
<code>write_pajek(G, path[, encoding])</code>	Write graph in Pajek format to path.
<code>parse_pajek(lines)</code>	Parse Pajek format graph from string or iterable.

9.12.2 read_pajek

read_pajek (*path*, *encoding*='UTF-8')

Read graph in Pajek format from path.

Parameters *path* (*file or string*) – File or filename to write. Filenames ending in .gz or .bz2 will be uncompressed.

Returns *G*

Return type NetworkX MultiGraph or MultiDiGraph.

Examples

```
>>> G=nx.path_graph(4)
>>> nx.write_pajek(G, "test.net")
>>> G=nx.read_pajek("test.net")
```

To create a Graph instead of a MultiGraph use

```
>>> G1=nx.Graph(G)
```

References

See <http://vlado.fmf.uni-lj.si/pub/networks/pajek/doc/draweps.htm> for format information.

9.12.3 write_pajek

write_pajek (*G*, *path*, *encoding*='UTF-8')

Write graph in Pajek format to path.

Parameters

- **G** (*graph*) – A Networkx graph
- **path** (*file or string*) – File or filename to write. Filenames ending in .gz or .bz2 will be compressed.

Examples

```
>>> G=nx.path_graph(4)
>>> nx.write_pajek(G, "test.net")
```

References

See <http://vlado.fmf.uni-lj.si/pub/networks/pajek/doc/draweps.htm> for format information.

9.12.4 parse_pajek

parse_pajek (*lines*)

Parse Pajek format graph from string or iterable.

Parameters **lines** (*string or iterable*) – Data in Pajek format.

Returns **G**

Return type NetworkX graph

See also:

`read_pajek()`

9.13 GIS Shapefile

9.13.1 Shapefile

Generates a networkx.DiGraph from point and line shapefiles.

“The Esri Shapefile or simply a shapefile is a popular geospatial vector data format for geographic information systems software. It is developed and regulated by Esri as a (mostly) open specification for data interoperability among Esri and other software products.” See <http://en.wikipedia.org/wiki/Shapefile> for additional information.

<code>read_shp(path[, simplify])</code>	Generates a networkx.DiGraph from shapefiles.
<code>write_shp(G, outdir)</code>	Writes a networkx.DiGraph to two shapefiles, edges and nodes.

9.13.2 read_shp

read_shp (*path, simplify=True*)

Generates a networkx.DiGraph from shapefiles. Point geometries are translated into nodes, lines into edges. Coordinate tuples are used as keys. Attributes are preserved, line geometries are simplified into start and end coordinates. Accepts a single shapefile or directory of many shapefiles.

“The Esri Shapefile or simply a shapefile is a popular geospatial vector data format for geographic information

systems software ⁷.”

Parameters

- **path** (*file or string*) – File, directory, or filename to read.
- **simplify** (*bool*) – If `True`, simplify line geometries to start and end coordinates. If `False`, and line feature geometry has multiple segments, the non-geometric attributes for that feature will be repeated for each edge comprising that feature.

Returns `G`

Return type NetworkX graph

Examples

```
>>> G=nx.read_shp('test.shp')
```

References

9.13.3 write_shp

write_shp (*G, outdir*)

Writes a networkx.DiGraph to two shapefiles, edges and nodes. Nodes and edges are expected to have a Well Known Binary (Wkb) or Well Known Text (Wkt) key in order to generate geometries. Also acceptable are nodes with a numeric tuple key (x,y).

“The Esri Shapefile or simply a shapefile is a popular geospatial vector data format for geographic information systems software ⁸.”

Parameters **outdir** (*directory path*) – Output directory for the two shapefiles.

Returns

Return type `None`

Examples

```
nx.write_shp(digraph, '/shapefiles') # doctest +SKIP
```

References

⁷ <http://en.wikipedia.org/wiki/Shapefile>

⁸ <http://en.wikipedia.org/wiki/Shapefile>

DRAWING

NetworkX provides basic functionality for visualizing graphs, but its main goal is to enable graph analysis rather than perform graph visualization. In the future, graph visualization functionality may be removed from NetworkX or only available as an add-on package.

Proper graph visualization is hard, and we highly recommend that people visualize their graphs with tools dedicated to that task. Notable examples of dedicated and fully-featured graph visualization tools are [Cytoscape](#), [Gephi](#), [Graphviz](#) and, for [LaTeX](#) typesetting, [PGF/TikZ](#). To use these and other such tools, you should export your NetworkX graph into a format that can be read by those tools. For example, Cytoscape can read the GraphML format, and so, `networkx.write_graphml(G)` might be an appropriate choice.

10.1 Matplotlib

10.1.1 Matplotlib

Draw networks with matplotlib.

See also:

matplotlib <http://matplotlib.org/>

pygraphviz <http://pygraphviz.github.io/>

<code>draw(G[, pos, ax, hold])</code>	Draw the graph G with Matplotlib.
<code>draw_networkx(G[, pos, arrows, with_labels])</code>	Draw the graph G using Matplotlib.
<code>draw_networkx_nodes(G, pos[, nodelist, ...])</code>	Draw the nodes of the graph G.
<code>draw_networkx_edges(G, pos[, edgelist, ...])</code>	Draw the edges of the graph G.
<code>draw_networkx_labels(G, pos[, labels, ...])</code>	Draw node labels on the graph G.
<code>draw_networkx_edge_labels(G, pos[, ...])</code>	Draw edge labels.
<code>draw_circular(G, **kwargs)</code>	Draw the graph G with a circular layout.
<code>draw_random(G, **kwargs)</code>	Draw the graph G with a random layout.
<code>draw_spectral(G, **kwargs)</code>	Draw the graph G with a spectral layout.
<code>draw_spring(G, **kwargs)</code>	Draw the graph G with a spring layout.
<code>draw_shell(G, **kwargs)</code>	Draw networkx graph with shell layout.
<code>draw_graphviz(G[, prog])</code>	Draw networkx graph with graphviz layout.

10.1.2 draw

draw (*G*, *pos=None*, *ax=None*, *hold=None*, ***kws*)
 Draw the graph G with Matplotlib.

Draw the graph as a simple representation with no node labels or edge labels and using the full Matplotlib figure area and no axis labels by default. See `draw_networkx()` for more full-featured drawing that allows title, axis labels etc.

Parameters

- **G** (*graph*) – A networkx graph
- **pos** (*dictionary, optional*) – A dictionary with nodes as keys and positions as values. If not specified a spring layout positioning will be computed. See `networkx.layout` for functions that compute node positions.
- **ax** (*Matplotlib Axes object, optional*) – Draw the graph in specified Matplotlib axes.
- **hold** (*bool, optional*) – Set the Matplotlib hold state. If True subsequent draw commands will be added to the current axes.
- ****kwds** – See `networkx.draw_networkx()` for a description of optional keywords.

Examples

```
>>> G=nx.dodecahedral_graph()
>>> nx.draw(G)
>>> nx.draw(G,pos=nx.spring_layout(G)) # use spring layout
```

See also:

```
draw_networkx(), draw_networkx_nodes(), draw_networkx_edges(),
draw_networkx_labels(), draw_networkx_edge_labels()
```

Notes

This function has the same name as `pylab.draw` and `pyplot.draw` so beware when using

```
>>> from networkx import *
```

since you might overwrite the `pylab.draw` function.

With pyplot use

```
>>> import matplotlib.pyplot as plt
>>> import networkx as nx
>>> G=nx.dodecahedral_graph()
>>> nx.draw(G) # networkx draw()
>>> plt.draw() # pyplot draw()
```

Also see the NetworkX drawing examples at <http://networkx.github.io/documentation/latest/gallery.html>

10.1.3 draw_networkx

draw_networkx (*G, pos=None, arrows=True, with_labels=True, **kwds*)

Draw the graph G using Matplotlib.

Draw the graph with Matplotlib with options for node positions, labeling, titles, and many other drawing features. See `draw()` for simple drawing without labels or axes.

Parameters

- **G** (*graph*) – A networkx graph

- **pos** (*dictionary, optional*) – A dictionary with nodes as keys and positions as values. If not specified a spring layout positioning will be computed. See `networkx.layout` for functions that compute node positions.
- **arrows** (*bool, optional (default=True)*) – For directed graphs, if True draw arrowheads.
- **with_labels** (*bool, optional (default=True)*) – Set to True to draw labels on the nodes.
- **ax** (*Matplotlib Axes object, optional*) – Draw the graph in the specified Matplotlib axes.
- **odelist** (*list, optional (default=G.nodes())*) – Draw only specified nodes
- **edgelist** (*list, optional (default=G.edges())*) – Draw only specified edges
- **node_size** (*scalar or array, optional (default=300)*) – Size of nodes. If an array is specified it must be the same length as `odelist`.
- **node_color** (*color string, or array of floats, (default='r')*) – Node color. Can be a single color format string, or a sequence of colors with the same length as `odelist`. If numeric values are specified they will be mapped to colors using the `cmap` and `vmin,vmax` parameters. See `matplotlib.scatter` for more details.
- **node_shape** (*string, optional (default='o')*) – The shape of the node. Specification is as `matplotlib.scatter` marker, one of 'so^>v<dph8'.
- **alpha** (*float, optional (default=1.0)*) – The node and edge transparency
- **cmap** (*Matplotlib colormap, optional (default=None)*) – Colormap for mapping intensities of nodes
- **vmin, vmax** (*float, optional (default=None)*) – Minimum and maximum for node colormap scaling
- **linewidths** (*[None | scalar | sequence]*) – Line width of symbol border (default =1.0)
- **width** (*float, optional (default=1.0)*) – Line width of edges
- **edge_color** (*color string, or array of floats (default='r')*) – Edge color. Can be a single color format string, or a sequence of colors with the same length as `edgelist`. If numeric values are specified they will be mapped to colors using the `edge_cmap` and `edge_vmin,edge_vmax` parameters.
- **edge_cmap** (*Matplotlib colormap, optional (default=None)*) – Colormap for mapping intensities of edges
- **edge_vmin, edge_vmax** (*floats, optional (default=None)*) – Minimum and maximum for edge colormap scaling
- **style** (*string, optional (default='solid')*) – Edge line style (solid|dashed|dotted,dashdot)
- **labels** (*dictionary, optional (default=None)*) – Node labels in a dictionary keyed by node of text labels
- **font_size** (*int, optional (default=12)*) – Font size for text labels
- **font_color** (*string, optional (default='k' black)*) – Font color string
- **font_weight** (*string, optional (default='normal')*) – Font weight
- **font_family** (*string, optional (default='sans-serif')*) – Font family
- **label** (*string, optional*) – Label for graph legend

Notes

For directed graphs, “arrows” (actually just thicker stubs) are drawn at the head end. Arrows can be turned off with keyword `arrows=False`. Yes, it is ugly but drawing proper arrows with Matplotlib this way is tricky.

Examples

```
>>> G=nx.dodecahedral_graph()
>>> nx.draw(G)
>>> nx.draw(G,pos=nx.spring_layout(G)) # use spring layout
```

```
>>> import matplotlib.pyplot as plt
>>> limits=plt.axis('off') # turn of axis
```

Also see the NetworkX drawing examples at <http://networkx.github.io/documentation/latest/gallery.html>

See also:

`draw()`, `draw_networkx_nodes()`, `draw_networkx_edges()`, `draw_networkx_labels()`,
`draw_networkx_edge_labels()`

10.1.4 draw_networkx_nodes

draw_networkx_nodes (*G*, *pos*, *odelist=None*, *node_size=300*, *node_color='r'*, *node_shape='o'*, *alpha=1.0*, *cmap=None*, *vmin=None*, *vmax=None*, *ax=None*, *linewidths=None*, *label=None*, ***kws*)

Draw the nodes of the graph *G*.

This draws only the nodes of the graph *G*.

Parameters

- **G** (*graph*) – A networkx graph
- **pos** (*dictionary*) – A dictionary with nodes as keys and positions as values. Positions should be sequences of length 2.
- **ax** (*Matplotlib Axes object, optional*) – Draw the graph in the specified Matplotlib axes.
- **odelist** (*list, optional*) – Draw only specified nodes (default `G.nodes()`)
- **node_size** (*scalar or array*) – Size of nodes (default=300). If an array is specified it must be the same length as `odelist`.
- **node_color** (*color string, or array of floats*) – Node color. Can be a single color format string (default='r'), or a sequence of colors with the same length as `odelist`. If numeric values are specified they will be mapped to colors using the `cmap` and `vmin,vmax` parameters. See `matplotlib.scatter` for more details.
- **node_shape** (*string*) – The shape of the node. Specification is as `matplotlib.scatter` marker, one of 'so^>v<dph8' (default='o').
- **alpha** (*float*) – The node transparency (default=1.0)
- **cmap** (*Matplotlib colormap*) – Colormap for mapping intensities of nodes (default=None)
- **vmin, vmax** (*floats*) – Minimum and maximum for node colormap scaling (default=None)
- **linewidths** (*[None | scalar | sequence]*) – Line width of symbol border (default =1.0)

- **label** (*[None| string]*) – Label for legend

Returns *PathCollection* of the nodes.

Return type matplotlib.collections.PathCollection

Examples

```
>>> G=nx.dodecahedral_graph()
>>> nodes=nx.draw_networkx_nodes(G,pos=nx.spring_layout(G))
```

Also see the NetworkX drawing examples at <http://networkx.github.io/documentation/latest/gallery.html>

See also:

```
draw(), draw_networkx(), draw_networkx_edges(), draw_networkx_labels(),
draw_networkx_edge_labels()
```

10.1.5 draw_networkx_edges

draw_networkx_edges (*G, pos, edgelist=None, width=1.0, edge_color='k', style='solid', alpha=1.0, edge_cmap=None, edge_vmin=None, edge_vmax=None, ax=None, arrows=True, label=None, **kwds*)

Draw the edges of the graph G.

This draws only the edges of the graph G.

Parameters

- **G** (*graph*) – A networkx graph
- **pos** (*dictionary*) – A dictionary with nodes as keys and positions as values. Positions should be sequences of length 2.
- **edgelist** (*collection of edge tuples*) – Draw only specified edges (default=G.edges())
- **width** (*float, or array of floats*) – Line width of edges (default=1.0)
- **edge_color** (*color string, or array of floats*) – Edge color. Can be a single color format string (default='r'), or a sequence of colors with the same length as edgelist. If numeric values are specified they will be mapped to colors using the edge_cmap and edge_vmin, edge_vmax parameters.
- **style** (*string*) – Edge line style (default='solid') (solid|dashed|dotted, dashdot)
- **alpha** (*float*) – The edge transparency (default=1.0)
- **cmap** (*edge*) – Colormap for mapping intensities of edges (default=None)
- **edge_vmin, edge_vmax** (*floats*) – Minimum and maximum for edge colormap scaling (default=None)
- **ax** (*Matplotlib Axes object, optional*) – Draw the graph in the specified Matplotlib axes.
- **arrows** (*bool, optional (default=True)*) – For directed graphs, if True draw arrowheads.
- **label** (*[None| string]*) – Label for legend

Returns *LineCollection* of the edges

Return type matplotlib.collection.LineCollection

Notes

For directed graphs, “arrows” (actually just thicker stubs) are drawn at the head end. Arrows can be turned off with keyword `arrows=False`. Yes, it is ugly but drawing proper arrows with Matplotlib this way is tricky.

Examples

```
>>> G=nx.dodecahedral_graph()
>>> edges=nx.draw_networkx_edges(G,pos=nx.spring_layout(G))
```

Also see the NetworkX drawing examples at <http://networkx.github.io/documentation/latest/gallery.html>

See also:

```
draw(), draw_networkx(), draw_networkx_nodes(), draw_networkx_labels(),
draw_networkx_edge_labels()
```

10.1.6 draw_networkx_labels

draw_networkx_labels (*G*, *pos*, *labels=None*, *font_size=12*, *font_color='k'*, *font_family='sans-serif'*,
font_weight='normal', *alpha=1.0*, *bbox=None*, *ax=None*, ***kwds*)

Draw node labels on the graph *G*.

Parameters

- **G** (*graph*) – A networkx graph
- **pos** (*dictionary*) – A dictionary with nodes as keys and positions as values. Positions should be sequences of length 2.
- **labels** (*dictionary, optional (default=None)*) – Node labels in a dictionary keyed by node of text labels
- **font_size** (*int*) – Font size for text labels (default=12)
- **font_color** (*string*) – Font color string (default='k' black)
- **font_family** (*string*) – Font family (default='sans-serif')
- **font_weight** (*string*) – Font weight (default='normal')
- **alpha** (*float*) – The text transparency (default=1.0)
- **ax** (*Matplotlib Axes object, optional*) – Draw the graph in the specified Matplotlib axes.

Returns *dict* of labels keyed on the nodes

Return type *dict*

Examples

```
>>> G=nx.dodecahedral_graph()
>>> labels=nx.draw_networkx_labels(G,pos=nx.spring_layout(G))
```

Also see the NetworkX drawing examples at <http://networkx.github.io/documentation/latest/gallery.html>

See also:

```
draw(), draw_networkx(), draw_networkx_nodes(), draw_networkx_edges(),
draw_networkx_edge_labels()
```


10.1.7 draw_networkx_edge_labels

draw_networkx_edge_labels (*G*, *pos*, *edge_labels=None*, *label_pos=0.5*, *font_size=10*, *font_color='k'*, *font_family='sans-serif'*, *font_weight='normal'*, *alpha=1.0*, *bbox=None*, *ax=None*, *rotate=True*, ***kwds*)

Draw edge labels.

Parameters

- **G** (*graph*) – A networkx graph
- **pos** (*dictionary*) – A dictionary with nodes as keys and positions as values. Positions should be sequences of length 2.
- **ax** (*Matplotlib Axes object, optional*) – Draw the graph in the specified Matplotlib axes.
- **alpha** (*float*) – The text transparency (default=1.0)
- **edge_labels** (*dictionary*) – Edge labels in a dictionary keyed by edge two-tuple of text labels (default=None). Only labels for the keys in the dictionary are drawn.
- **label_pos** (*float*) – Position of edge label along edge (0=head, 0.5=center, 1=tail)
- **font_size** (*int*) – Font size for text labels (default=12)
- **font_color** (*string*) – Font color string (default='k' black)
- **font_weight** (*string*) – Font weight (default='normal')
- **font_family** (*string*) – Font family (default='sans-serif')
- **bbox** (*Matplotlib bbox*) – Specify text box shape and colors.
- **clip_on** (*bool*) – Turn on clipping at axis boundaries (default=True)

Returns *dict* of labels keyed on the edges

Return type *dict*

Examples

```
>>> G=nx.dodecahedral_graph()
>>> edge_labels=nx.draw_networkx_edge_labels(G,pos=nx.spring_layout(G))
```

Also see the NetworkX drawing examples at <http://networkx.github.io/documentation/latest/gallery.html>

See also:

```
draw(), draw_networkx(), draw_networkx_nodes(), draw_networkx_edges(),
draw_networkx_labels()
```

10.1.8 draw_circular

draw_circular (*G*, ***kwargs*)

Draw the graph *G* with a circular layout.

Parameters

- **G** (*graph*) – A networkx graph
- ****kwargs** – See `networkx.draw_networkx()` for a description of optional keywords, with the exception of the `pos` parameter which is not used by this function.

10.1.9 draw_random

draw_random (*G*, ***kwargs*)

Draw the graph *G* with a random layout.

Parameters

- **G** (*graph*) – A networkx graph
- ****kwargs** – See networkx.draw_networkx() for a description of optional keywords, with the exception of the pos parameter which is not used by this function.

10.1.10 draw_spectral

draw_spectral (*G*, ***kwargs*)

Draw the graph *G* with a spectral layout.

Parameters

- **G** (*graph*) – A networkx graph
- ****kwargs** – See networkx.draw_networkx() for a description of optional keywords, with the exception of the pos parameter which is not used by this function.

10.1.11 draw_spring

draw_spring (*G*, ***kwargs*)

Draw the graph *G* with a spring layout.

Parameters

- **G** (*graph*) – A networkx graph
- ****kwargs** – See networkx.draw_networkx() for a description of optional keywords, with the exception of the pos parameter which is not used by this function.

10.1.12 draw_shell

draw_shell (*G*, ***kwargs*)

Draw networkx graph with shell layout.

Parameters

- **G** (*graph*) – A networkx graph
- ****kwargs** – See networkx.draw_networkx() for a description of optional keywords, with the exception of the pos parameter which is not used by this function.

10.1.13 draw_graphviz

draw_graphviz (*G*, *prog='neato'*, ***kwargs*)

Draw networkx graph with graphviz layout.

Parameters

- **G** (*graph*) – A networkx graph
- **prog** (*string, optional*) – Name of Graphviz layout program

- ****kwargs** – See `networkx.draw_networkx()` for a description of optional keywords.

10.2 Graphviz AGraph (dot)

10.2.1 Graphviz AGraph

Interface to pygraphviz AGraph class.

Examples

```
>>> G=nx.complete_graph(5)
>>> A=nx.to_agraph(G)
>>> H=nx.from_agraph(A)
```

See also:

Pygraphviz <http://pygraphviz.github.io/>

<code>from_agraph(A[, create_using])</code>	Return a NetworkX Graph or DiGraph from a PyGraphviz graph.
<code>to_agraph(N)</code>	Return a pygraphviz graph from a NetworkX graph N.
<code>write_dot(G, path)</code>	Write NetworkX graph G to Graphviz dot format on path.
<code>read_dot(path)</code>	Return a NetworkX graph from a dot file on path.
<code>graphviz_layout(G[, prog, root, args])</code>	Create node positions for G using Graphviz.
<code>pygraphviz_layout(G[, prog, root, args])</code>	Create node positions for G using Graphviz.

10.2.2 from_agraph

from_agraph (*A*, *create_using=None*)

Return a NetworkX Graph or DiGraph from a PyGraphviz graph.

Parameters

- **A** (*PyGraphviz AGraph*) – A graph created with PyGraphviz
- **create_using** (*NetworkX graph class instance*) – The output is created using the given graph class instance

Examples

```
>>> K5=nx.complete_graph(5)
>>> A=nx.to_agraph(K5)
>>> G=nx.from_agraph(A)
>>> G=nx.from_agraph(A)
```

Notes

The Graph G will have a dictionary `G.graph_attr` containing the default graphviz attributes for graphs, nodes and edges.

Default node attributes will be in the dictionary `G.node_attr` which is keyed by node.

Edge attributes will be returned as edge data in G. With `edge_attr=False` the edge data will be the Graphviz edge weight attribute or the value 1 if no edge weight attribute is found.

10.2.3 to_agraph

to_agraph (*N*)

Return a pygraphviz graph from a NetworkX graph *N*.

Parameters *N* (*NetworkX graph*) – A graph created with NetworkX

Examples

```
>>> K5=nx.complete_graph(5)
>>> A=nx.to_agraph(K5)
```

Notes

If *N* has an dict *N.graph_attr* an attempt will be made first to copy properties attached to the graph (see `from_agraph`) and then updated with the calling arguments if any.

10.2.4 write_dot

write_dot (*G*, *path*)

Write NetworkX graph *G* to Graphviz dot format on *path*.

Parameters

- **G** (*graph*) – A networkx graph
- **path** (*filename*) – Filename or file handle to write

10.2.5 read_dot

read_dot (*path*)

Return a NetworkX graph from a dot file on *path*.

Parameters *path* (*file or string*) – File name or file handle to read.

10.2.6 graphviz_layout

graphviz_layout (*G*, *prog='neato'*, *root=None*, *args=''*)

Create node positions for *G* using Graphviz.

Parameters

- **G** (*NetworkX graph*) – A graph created with NetworkX
- **prog** (*string*) – Name of Graphviz layout program
- **root** (*string, optional*) – Root node for twopi layout
- **args** (*string, optional*) – Extra arguments to Graphviz layout program
- **Returns** (*dictionary*) – Dictionary of x,y, positions keyed by node.

Examples

```
>>> G=nx.petersen_graph()
>>> pos=nx.graphviz_layout(G)
>>> pos=nx.graphviz_layout(G,prog='dot')
```

Notes

This is a wrapper for `pygraphviz_layout`.

10.2.7 pygraphviz_layout

pygraphviz_layout (*G*, *prog*='neato', *root*=None, *args*='')

Create node positions for *G* using Graphviz.

Parameters

- **G** (*NetworkX graph*) – A graph created with NetworkX
- **prog** (*string*) – Name of Graphviz layout program
- **root** (*string, optional*) – Root node for twopi layout
- **args** (*string, optional*) – Extra arguments to Graphviz layout program
- **Returns** (*dictionary*) – Dictionary of x,y, positions keyed by node.

Examples

```
>>> G=nx.petersen_graph()
>>> pos=nx.graphviz_layout(G)
>>> pos=nx.graphviz_layout(G,prog='dot')
```

10.3 Graphviz with pydot

10.3.1 Pydot

Import and export NetworkX graphs in Graphviz dot format using pydot.

Either this module or `nx_pygraphviz` can be used to interface with graphviz.

See also:

Pydot <http://code.google.com/p/pydot/>

Graphviz <http://www.research.att.com/sw/tools/graphviz/>

DOT

<code>from_pydot(P)</code>	Return a NetworkX graph from a Pydot graph.
<code>to_pydot(N[, strict])</code>	Return a pydot graph from a NetworkX graph N.
<code>write_dot(G, path)</code>	Write NetworkX graph G to Graphviz dot format on path.
<code>read_dot(path)</code>	Return a NetworkX MultiGraph or MultiDiGraph from a dot file on path.
Continued on next page	

Table 10.3 – continued from previous page

<code>graphviz_layout(G[, prog, root])</code>	Create node positions using Pydot and Graphviz.
<code>pydot_layout(G[, prog, root])</code>	Create node positions using Pydot and Graphviz.

10.3.2 from_pydot

from_pydot (*P*)

Return a NetworkX graph from a Pydot graph.

Parameters *P* (*Pydot graph*) – A graph created with Pydot

Returns *G* – A MultiGraph or MultiDiGraph.

Return type NetworkX multigraph

Examples

```
>>> K5=nx.complete_graph(5)
>>> A=nx.to_pydot(K5)
>>> G=nx.from_pydot(A) # return MultiGraph
>>> G=nx.Graph(nx.from_pydot(A)) # make a Graph instead of MultiGraph
```

10.3.3 to_pydot

to_pydot (*N*, *strict=True*)

Return a pydot graph from a NetworkX graph *N*.

Parameters *N* (*NetworkX graph*) – A graph created with NetworkX

Examples

```
>>> K5=nx.complete_graph(5)
>>> P=nx.to_pydot(K5)
```

Notes

10.3.4 write_dot

write_dot (*G*, *path*)

Write NetworkX graph *G* to Graphviz dot format on *path*.

Path can be a string or a file handle.

10.3.5 read_dot

read_dot (*path*)

Return a NetworkX MultiGraph or MultiDiGraph from a dot file on *path*.

Parameters *path* (*filename or file handle*) –

Returns *G* – A MultiGraph or MultiDiGraph.

Return type NetworkX multigraph

Notes

Use `G=nx.Graph(nx.read_dot(path))` to return a Graph instead of a MultiGraph.

10.3.6 graphviz_layout

graphviz_layout (*G*, *prog*='neato', *root*=None, ***kws*)

Create node positions using Pydot and Graphviz.

Returns a dictionary of positions keyed by node.

Examples

```
>>> G=nx.complete_graph(4)
>>> pos=nx.graphviz_layout(G)
>>> pos=nx.graphviz_layout(G,prog='dot')
```

Notes

This is a wrapper for `pydot_layout`.

10.3.7 pydot_layout

pydot_layout (*G*, *prog*='neato', *root*=None, ***kws*)

Create node positions using Pydot and Graphviz.

Returns a dictionary of positions keyed by node.

Examples

```
>>> G=nx.complete_graph(4)
>>> pos=nx.pydot_layout(G)
>>> pos=nx.pydot_layout(G,prog='dot')
```

10.4 Graph Layout

10.4.1 Layout

Node positioning algorithms for graph drawing.

<code>circular_layout</code> (<i>G</i> [, <i>dim</i> , <i>scale</i> , <i>center</i>])	Position nodes on a circle.
<code>random_layout</code> (<i>G</i> [, <i>dim</i> , <i>center</i>])	Position nodes uniformly at random in the unit square.
<code>shell_layout</code> (<i>G</i> [, <i>nlist</i> , <i>dim</i> , <i>scale</i> , <i>center</i>])	Position nodes in concentric circles.
<code>spring_layout</code> (<i>G</i> [, <i>dim</i> , <i>k</i> , <i>pos</i> , <i>fixed</i> , ...])	Position nodes using Fruchterman-Reingold force-directed algorithm.
<code>spectral_layout</code> (<i>G</i> [, <i>dim</i> , <i>weight</i> , <i>scale</i> , <i>center</i>])	Position nodes using the eigenvectors of the graph Laplacian.

10.4.2 circular_layout

circular_layout (*G*, *dim*=2, *scale*=1, *center*=None)

Position nodes on a circle.

Parameters

- **G** (*NetworkX graph or list of nodes*) –
- **dim** (*int*) – Dimension of layout, currently only dim=2 is supported
- **scale** (*float*) – Scale factor for positions
- **center** (*array-like or None*) – Coordinate pair around which to center the layout.

Returns A dictionary of positions keyed by node

Return type `dict`

Examples

```
>>> G=nx.path_graph(4)
>>> pos=nx.circular_layout(G)
```

This algorithm currently only works in two dimensions and does not try to minimize edge crossings.

10.4.3 random_layout

random_layout (*G*, *dim*=2, *center*=None)

Position nodes uniformly at random in the unit square.

For every node, a position is generated by choosing each of dim coordinates uniformly at random on the interval [0.0, 1.0).

NumPy (<http://scipy.org>) is required for this function.

Parameters

- **G** (*NetworkX graph or list of nodes*) – A position will be assigned to every node in G.
- **dim** (*int*) – Dimension of layout.
- **center** (*array-like or None*) – Coordinate pair around which to center the layout.

Returns `pos` – A dictionary of positions keyed by node

Return type `dict`

Examples

```
>>> G = nx.lollipop_graph(4, 3)
>>> pos = nx.random_layout(G)
```

10.4.4 shell_layout

shell_layout (*G*, *nlist*=None, *dim*=2, *scale*=1, *center*=None)

Position nodes in concentric circles.

Parameters

- **G** (*NetworkX graph or list of nodes*) –
- **nlist** (*list of lists*) – List of node lists for each shell.
- **dim** (*int*) – Dimension of layout, currently only dim=2 is supported
- **scale** (*float*) – Scale factor for positions
- **center** (*array-like or None*) – Coordinate pair around which to center the layout.

Returns A dictionary of positions keyed by node

Return type `dict`

Examples

```
>>> G = nx.path_graph(4)
>>> shells = [[0], [1,2,3]]
>>> pos = nx.shell_layout(G, shells)
```

This algorithm currently only works in two dimensions and does not try to minimize edge crossings.

10.4.5 spring_layout

spring_layout (*G, dim=2, k=None, pos=None, fixed=None, iterations=50, weight='weight', scale=1.0, center=None*)

Position nodes using Fruchterman-Reingold force-directed algorithm.

Parameters

- **G** (*NetworkX graph or list of nodes*) –
- **dim** (*int*) – Dimension of layout
- **k** (*float (default=None)*) – Optimal distance between nodes. If None the distance is set to $1/\sqrt{n}$ where n is the number of nodes. Increase this value to move nodes farther apart.

pos [dict or None optional (default=None)] Initial positions for nodes as a dictionary with node as keys and values as a list or tuple. If None, then use random initial positions.

fixed [list or None optional (default=None)] Nodes to keep fixed at initial position.

iterations [int optional (default=50)] Number of iterations of spring-force relaxation

weight [string or None optional (default='weight')] The edge attribute that holds the numerical value used for the edge weight. If None, then all edge weights are 1.

scale [float (default=1.0)] Scale factor for positions. The nodes are positioned in a box of size [0,scale] x [0,scale].

center [array-like or None] Coordinate pair around which to center the layout.

Returns A dictionary of positions keyed by node

Return type `dict`

Examples

```
>>> G=nx.path_graph(4)
>>> pos=nx.spring_layout(G)
```

The same using longer function name >>> pos=nx.fruchterman_reingold_layout(G)

10.4.6 spectral_layout

spectral_layout (*G*, *dim*=2, *weight*='weight', *scale*=1, *center*=None)

Position nodes using the eigenvectors of the graph Laplacian.

Parameters

- **G** (*NetworkX graph or list of nodes*) –
- **dim** (*int*) – Dimension of layout
- **weight** (*string or None optional (default='weight')*) – The edge attribute that holds the numerical value used for the edge weight. If None, then all edge weights are 1.
- **scale** (*float*) – Scale factor for positions
- **center** (*array-like or None*) – Coordinate pair around which to center the layout.

Returns A dictionary of positions keyed by node

Return type `dict`

Examples

```
>>> G=nx.path_graph(4)
>>> pos=nx.spectral_layout(G)
```

Notes

Directed graphs will be considered as undirected graphs when positioning the nodes.

For larger graphs (>500 nodes) this will use the SciPy sparse eigenvalue solver (ARPACK).

EXCEPTIONS

11.1 Exceptions

Base exceptions and errors for NetworkX.

class NetworkXException

Base class for exceptions in NetworkX.

class NetworkXError

Exception for a serious error in NetworkX

class NetworkXPointlessConcept

Harary, F. and Read, R. "Is the Null Graph a Pointless Concept?" In Graphs and Combinatorics Conference, George Washington University. New York: Springer-Verlag, 1973.

class NetworkXAlgorithmError

Exception for unexpected termination of algorithms.

class NetworkXUnfeasible

Exception raised by algorithms trying to solve a problem instance that has no feasible solution.

class NetworkXNoPath

Exception for algorithms that should return a path when running on graphs where such a path does not exist.

class NetworkXUnbounded

Exception raised by algorithms trying to solve a maximization or a minimization problem instance that is unbounded.

12.1 Helper Functions

Miscellaneous Helpers for NetworkX.

These are not imported into the base networkx namespace but can be accessed, for example, as

```
>>> import networkx
>>> networkx.utils.is_string_like('spam')
True
```

<code>is_string_like(obj)</code>	Check if obj is string.
<code>flatten(obj[, result])</code>	Return flattened version of (possibly nested) iterable object.
<code>iterable(obj)</code>	Return True if obj is iterable with a well-defined len().
<code>is_list_of_ints(intlist)</code>	Return True if list is a list of ints.
<code>make_str(x)</code>	Return the string representation of t.
<code>generate_unique_node()</code>	Generate a unique node label.
<code>default_opener(filename)</code>	Opens <i>filename</i> using system's default program.

12.1.1 is_string_like

is_string_like (*obj*)
Check if obj is string.

12.1.2 flatten

flatten (*obj*, *result=None*)
Return flattened version of (possibly nested) iterable object.

12.1.3 iterable

iterable (*obj*)
Return True if obj is iterable with a well-defined len().

12.1.4 is_list_of_ints

is_list_of_ints (*intlist*)
Return True if list is a list of ints.

12.1.5 make_str

make_str (*x*)

Return the string representation of *t*.

12.1.6 generate_unique_node

generate_unique_node ()

Generate a unique node label.

12.1.7 default_opener

default_opener (*filename*)

Opens *filename* using system's default program.

Parameters **filename** (*str*) – The path of the file to be opened.

12.2 Data Structures and Algorithms

Union-find data structure.

UnionFind.union(*objects) Find the sets containing the objects and merge them all.

12.2.1 union

UnionFind.**union** (**objects*)

Find the sets containing the objects and merge them all.

12.3 Random Sequence Generators

Utilities for generating random numbers, random sequences, and random selections.

<i>create_degree_sequence</i> (<i>n</i> [, <i>sfunction</i> , <i>max_tries</i>])	
<i>pareto_sequence</i> (<i>n</i> [, <i>exponent</i>])	Return sample sequence of length <i>n</i> from a Pareto distribution.
<i>powerlaw_sequence</i> (<i>n</i> [, <i>exponent</i>])	Return sample sequence of length <i>n</i> from a power law distribution.
<i>uniform_sequence</i> (<i>n</i>)	Return sample sequence of length <i>n</i> from a uniform distribution.
<i>cumulative_distribution</i> (<i>distribution</i>)	Return normalized cumulative distribution from discrete distribution.
<i>discrete_sequence</i> (<i>n</i> [, <i>distribution</i> , ...])	Return sample sequence of length <i>n</i> from a given discrete distribution or
<i>zipf_sequence</i> (<i>n</i> [, <i>alpha</i> , <i>xmin</i>])	Return a sample sequence of length <i>n</i> from a Zipf distribution with expo
<i>zipf_rv</i> (<i>alpha</i> [, <i>xmin</i> , <i>seed</i>])	Return a random value chosen from the Zipf distribution.
<i>random_weighted_sample</i> (<i>mapping</i> , <i>k</i>)	Return <i>k</i> items without replacement from a weighted sample.
<i>weighted_choice</i> (<i>mapping</i>)	Return a single element from a weighted sample.

12.3.1 create_degree_sequence

create_degree_sequence (*n*, *sfunction*=None, *max_tries*=50, ***kws*)

12.3.2 `pareto_sequence`

pareto_sequence (*n*, *exponent*=1.0)

Return sample sequence of length *n* from a Pareto distribution.

12.3.3 `powerlaw_sequence`

powerlaw_sequence (*n*, *exponent*=2.0)

Return sample sequence of length *n* from a power law distribution.

12.3.4 `uniform_sequence`

uniform_sequence (*n*)

Return sample sequence of length *n* from a uniform distribution.

12.3.5 `cumulative_distribution`

cumulative_distribution (*distribution*)

Return normalized cumulative distribution from discrete distribution.

12.3.6 `discrete_sequence`

discrete_sequence (*n*, *distribution*=None, *cdistribution*=None)

Return sample sequence of length *n* from a given discrete distribution or discrete cumulative distribution.

One of the following must be specified.

distribution = histogram of values, will be normalized

cdistribution = normalized discrete cumulative distribution

12.3.7 `zipf_sequence`

zipf_sequence (*n*, *alpha*=2.0, *xmin*=1)

Return a sample sequence of length *n* from a Zipf distribution with exponent parameter *alpha* and minimum value *xmin*.

See also:

`zipf_rv()`

12.3.8 `zipf_rv`

zipf_rv (*alpha*, *xmin*=1, *seed*=None)

Return a random value chosen from the Zipf distribution.

The return value is an integer drawn from the probability distribution ::math:

$$p(x) = \frac{x^{-\alpha}}{\zeta(\alpha, x_{\min})},$$

where $\zeta(\alpha, x_{\min})$ is the Hurwitz zeta function.

Parameters

- **alpha** (*float*) – Exponent value of the distribution
- **xmin** (*int*) – Minimum value
- **seed** (*int*) – Seed value for random number generator

Returns *x* – Random value from Zipf distribution

Return type *int*

Raises *ValueError* – If *xmin* < 1 or If *alpha* <= 1

Notes

The rejection algorithm generates random values for a the power-law distribution in uniformly bounded expected time dependent on parameters. See [1] for details on its operation.

Examples

```
>>> nx.zipf_rv(alpha=2, xmin=3, seed=42)
```

References

..[1] Luc Devroye, **Non-Uniform Random Variate Generation**, Springer-Verlag, New York, 1986.

12.3.9 random_weighted_sample

random_weighted_sample (*mapping*, *k*)

Return *k* items without replacement from a weighted sample.

The input is a dictionary of items with weights as values.

12.3.10 weighted_choice

weighted_choice (*mapping*)

Return a single element from a weighted sample.

The input is a dictionary of items with weights as values.

12.4 Decorators

`open_file(path_arg[, mode])` Decorator to ensure clean opening and closing of files.

12.4.1 open_file

open_file (*path_arg*, *mode*='r')

Decorator to ensure clean opening and closing of files.

Parameters

- **path_arg** (*int*) – Location of the path argument in args. Even if the argument is a named positional argument (with a default value), you must specify its index as a positional argument.
- **mode** (*str*) – String for opening mode.

Returns `_open_file` – Function which cleanly executes the io.

Return type *function*

Examples

Decorate functions like this:

```
@open_file(0, 'r')
def read_function(pathname):
    pass

@open_file(1, 'w')
def write_function(G, pathname):
    pass

@open_file(1, 'w')
def write_function(G, pathname='graph.dot')
    pass

@open_file('path', 'w+')
def another_function(arg, **kwargs):
    path = kwargs['path']
    pass
```

12.5 Cuthill-McKee Ordering

Cuthill-McKee ordering of graph nodes to produce sparse matrices

<code>cuthill_mckee_ordering(G[, heuristic])</code>	Generate an ordering (permutation) of the graph nodes to make a sparse matrix.
<code>reverse_cuthill_mckee_ordering(G[, heuristic])</code>	Generate an ordering (permutation) of the graph nodes to make a sparse matrix.

12.5.1 cuthill_mckee_ordering

cuthill_mckee_ordering (*G*, *heuristic=None*)

Generate an ordering (permutation) of the graph nodes to make a sparse matrix.

Uses the Cuthill-McKee heuristic (based on breadth-first search) ¹.

Parameters

- **G** (*graph*) – A NetworkX graph
- **heuristic** (*function, optional*) – Function to choose starting node for RCM algorithm. If None a node from a pseudo-peripheral pair is used. A user-defined function can be supplied that takes a graph object and returns a single node.

¹ E. Cuthill and J. McKee. Reducing the bandwidth of sparse symmetric matrices, In Proc. 24th Nat. Conf. ACM, pages 157-172, 1969. <http://doi.acm.org/10.1145/800195.805928>

Returns nodes – Generator of nodes in Cuthill-McKee ordering.

Return type generator

Examples

```
>>> from networkx.utils import cuthill_mckee_ordering
>>> G = nx.path_graph(4)
>>> rcm = list(cuthill_mckee_ordering(G))
>>> A = nx.adjacency_matrix(G, nodelist=rcm)
```

Smallest degree node as heuristic function:

```
>>> def smallest_degree(G):
...     return min(G, key=G.degree)
>>> rcm = list(cuthill_mckee_ordering(G, heuristic=smallest_degree))
```

See also:

`reverse_cuthill_mckee_ordering()`

Notes

The optimal solution the the bandwidth reduction is NP-complete ².

References

12.5.2 reverse_cuthill_mckee_ordering

reverse_cuthill_mckee_ordering(*G*, *heuristic=None*)

Generate an ordering (permutation) of the graph nodes to make a sparse matrix.

Uses the reverse Cuthill-McKee heuristic (based on breadth-first search) ³.

Parameters

- **G** (*graph*) – A NetworkX graph
- **heuristic** (*function, optional*) – Function to choose starting node for RCM algorithm. If None a node from a psuedo-peripheral pair is used. A user-defined function can be supplied that takes a graph object and returns a single node.

Returns nodes – Generator of nodes in reverse Cuthill-McKee ordering.

Return type generator

Examples

```
>>> from networkx.utils import reverse_cuthill_mckee_ordering
>>> G = nx.path_graph(4)
>>> rcm = list(reverse_cuthill_mckee_ordering(G))
>>> A = nx.adjacency_matrix(G, nodelist=rcm)
```

² Steven S. Skiena. 1997. The Algorithm Design Manual. Springer-Verlag New York, Inc., New York, NY, USA.

³ E. Cuthill and J. McKee. Reducing the bandwidth of sparse symmetric matrices, In Proc. 24th Nat. Conf. ACM, pages 157-72, 1969.
<http://doi.acm.org/10.1145/800195.805928>

Smallest degree node as heuristic function:

```
>>> def smallest_degree(G):
...     return min(G, key=G.degree)
>>> rcm = list(reverse_cuthill_mckee_ordering(G, heuristic=smallest_degree))
```

See also:

`cuthill_mckee_ordering()`

Notes

The optimal solution the the bandwidth reduction is NP-complete ⁴.

References

12.6 Context Managers

`reversed(*args, **kwargs)` A context manager for temporarily reversing a directed graph in place.

12.6.1 reversed

reversed (**args, **kwargs*)

A context manager for temporarily reversing a directed graph in place.

This is a no-op for undirected graphs.

Parameters *G* (*graph*) – A NetworkX graph.

⁴ Steven S. Skiena. 1997. The Algorithm Design Manual. Springer-Verlag New York, Inc., New York, NY, USA.

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To cite NetworkX please use the following publication:

Aric A. Hagberg, Daniel A. Schult and Pieter J. Swart, “Exploring network structure, dynamics, and function using NetworkX”, in *Proceedings of the 7th Python in Science Conference (SciPy2008)*, Gael Varoquaux, Travis Vaught, and Jarrod Millman (Eds), (Pasadena, CA USA), pp. 11–15, Aug 2008

CREDITS

NetworkX was originally written by Aric Hagberg, Dan Schult, and Pieter Swart, and has been developed with the help of many others. Thanks to everyone who has improved NetworkX by contributing code, bug reports (and fixes), documentation, and input on design, features, and the future of NetworkX.

15.1 Contributions

This section aims to provide a list of people and projects that have contributed to `networkx`. It is intended to be an *inclusive* list, and anyone who has contributed and wishes to make that contribution known is welcome to add an entry into this file. Generally, no name should be added to this list without the approval of the person associated with that name.

Creating a comprehensive list of contributors can be difficult, and the list within this file is almost certainly incomplete. Contributors include testers, bug reporters, contributors who wish to remain anonymous, funding sources, academic advisors, end users, and even build/integration systems (such as [TravisCI](#), [coveralls](#), and [readthedocs](#)).

Do you want to make your contribution known? If you have commit access, edit this file and add your name. If you do not have commit access, feel free to open an [issue](#), submit a [pull request](#), or get in contact with one of the official team [members](#).

A supplementary (but still incomplete) list of contributors is given by the list of names that have commits in `networkx`'s [git](#) repository. This can be obtained via:

```
git log --raw | grep "^Author: " | sort | uniq
```

A historical, partial listing of contributors and their contributions to some of the earlier versions of NetworkX can be found [here](#).

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Dan Schult
Pieter Swart

15.1.2 Contributors

Optionally, add your desired name and include a few relevant links. The order is partially historical, and now, mostly arbitrary.

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- Hernan Rozenfeld
- Brendt Wohlberg
- Jim Bagrow
- Holly Johnsen
- Arnar Flatberg
- Chris Myers
- Joel Miller
- Keith Briggs
- Ignacio Rozada
- Phillipp Pagel
- Sverre Sundsdal
- Ross M. Richardson
- Eben Kenah
- Sasha Gutfriend
- Udi Weinsberg
- Matteo Dell’Amico
- Andrew Conway
- Raf Guns
- Salim Fadhley
- Matteo Dell’Amico
- Fabrice Desclaux
- Arpad Horvath
- Minh Van Nguyen
- Willem Ligtenberg
- Loïc Séguin-C.
- Paul McGuire
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- Ryan Nelson, GitHub: [rnelsonchem](#)

15.2 Support

`networkx` and those who have contributed to `networkx` have received support throughout the years from a variety of sources. We list them below. If you have provided support to `networkx` and a support acknowledgment does not appear below, please help us remedy the situation, and similarly, please let us know if you'd like something modified or corrected.

15.2.1 Research Groups

`networkx` acknowledges support from the following:

- [Center for Nonlinear Studies](#), Los Alamos National Laboratory, PI: Aric Hagberg
- [Open Source Programs Office](#), Google
- [Complexity Sciences Center](#), Department of Physics, University of California-Davis, PI: James P. Crutchfield
- [Center for Complexity and Collective Computation](#), Wisconsin Institute for Discovery, University of Wisconsin-Madison, PIs: Jessica C. Flack and David C. Krakauer

15.2.2 Funding

networkx acknowledges support from the following:

- Google Summer of Code via Python Software Foundation
- U.S. Army Research Office grant W911NF-12-1-0288
- DARPA Physical Intelligence Subcontract No. 9060-000709
- NSF Grant No. PHY-0748828
- John Templeton Foundation through a grant to the Santa Fe Institute to study complexity
- U.S. Army Research Laboratory and the U.S. Army Research Office under contract number W911NF-13-1-0340

GLOSSARY

dictionary A Python dictionary maps keys to values. Also known as “hashes”, or “associative arrays”. See <http://docs.python.org/tutorial/datastructures.html#dictionaries>

ebunch An iterable container of edge tuples like a list, iterator, or file.

edge Edges are either two-tuples of nodes (u,v) or three tuples of nodes with an edge attribute dictionary (u,v,dict).

edge attribute Edges can have arbitrary Python objects assigned as attributes by using keyword/value pairs when adding an edge assigning to the `G.edge[u][v]` attribute dictionary for the specified edge u-v.

hashable An object is hashable if it has a hash value which never changes during its lifetime (it needs a `__hash__()` method), and can be compared to other objects (it needs an `__eq__()` or `__cmp__()` method). Hashable objects which compare equal must have the same hash value.

Hashability makes an object usable as a dictionary key and a set member, because these data structures use the hash value internally.

All of Python’s immutable built-in objects are hashable, while no mutable containers (such as lists or dictionaries) are. Objects which are instances of user-defined classes are hashable by default; they all compare unequal, and their hash value is their `id()`.

Definition from <http://docs.python.org/glossary.html>

nbunch An nbunch is any iterable container of nodes that is not itself a node in the graph. It can be an iterable or an iterator, e.g. a list, set, graph, file, etc..

node A node can be any hashable Python object except None.

node attribute Nodes can have arbitrary Python objects assigned as attributes by using keyword/value pairs when adding a node or assigning to the `G.node[n]` attribute dictionary for the specified node n.

a

networkx.algorithms.approximation, 25
 networkx.algorithms.approximation.clique, 29
 networkx.algorithms.approximation.clustering_coefficient, 30
 networkx.algorithms.approximation.connectivity, 25
 networkx.algorithms.approximation.dominating_set, 30
 networkx.algorithms.approximation.independent_set, 31
 networkx.algorithms.approximation.kcomponents, 27
 networkx.algorithms.approximation.matching, 32
 networkx.algorithms.approximation.ramsey, 33
 networkx.algorithms.approximation.vertex_cover, 33
 networkx.algorithms.assortativity, 34
 networkx.algorithms.bipartite, 34
 networkx.algorithms.bipartite.basic, 35
 networkx.algorithms.bipartite.centralities, 53
 networkx.algorithms.bipartite.cluster, 48
 networkx.algorithms.bipartite.generators, 56
 networkx.algorithms.bipartite.matching, 39
 networkx.algorithms.bipartite.matrix, 41
 networkx.algorithms.bipartite.projection, 42
 networkx.algorithms.bipartite.redundancy, 52
 networkx.algorithms.bipartite.spectral, 47
 networkx.algorithms.block, 61
 networkx.algorithms.boundary, 61
 networkx.algorithms.centralities, 63
 networkx.algorithms.chordal.chordal_alg, 64
 networkx.algorithms.clique, 67
 networkx.algorithms.cluster, 70
 networkx.algorithms.coloring, 74
 networkx.algorithms.community, 74
 networkx.algorithms.community.kclique, 74
 networkx.algorithms.components, 75
 networkx.algorithms.components.attracting, 84
 networkx.algorithms.components.biconnected, 85
 networkx.algorithms.components.connected, 75
 networkx.algorithms.components.semiconnected, 90
 networkx.algorithms.components.strongly_connected, 77
 networkx.algorithms.components.weakly_connected, 81
 networkx.algorithms.connectivity, 91
 networkx.algorithms.connectivity.connectivity, 93
 networkx.algorithms.connectivity.cuts, 101
 networkx.algorithms.connectivity.kcomponents, 91
 networkx.algorithms.connectivity.kcutsets, 92
 networkx.algorithms.connectivity.stoerwagner, 107
 networkx.algorithms.connectivity.utils, 108
 networkx.algorithms.core, 109
 networkx.algorithms.cycles, 112
 networkx.algorithms.dag, 115
 networkx.algorithms.distance_measures, 119
 networkx.algorithms.distance_regular, 121
 networkx.algorithms.dominance, 123

`networkx.algorithms.dominating`, 124
`networkx.algorithms.euler`, 125
`networkx.algorithms.flow`, 126
`networkx.algorithms.graphical`, 127
`networkx.algorithms.hierarchy`, 130
`networkx.algorithms.hybrid`, 131
`networkx.algorithms.isolate`, 132
`networkx.algorithms.isomorphism`, 133
`networkx.algorithms.isomorphism.isomorphvf2`,
133
`networkx.algorithms.link_analysis.hits_alg`,
139
`networkx.algorithms.link_analysis.pagerank_alg`,
135
`networkx.algorithms.link_prediction`, 142
`networkx.algorithms.matching`, 148
`networkx.algorithms.minors`, 149
`networkx.algorithms.mis`, 153
`networkx.algorithms.mst`, 153
`networkx.algorithms.operators.all`, 158
`networkx.algorithms.operators.binary`,
156
`networkx.algorithms.operators.product`,
160
`networkx.algorithms.operators.unary`, 155
`networkx.algorithms.richclub`, 164
`networkx.algorithms.shortest_paths.astar`,
181
`networkx.algorithms.shortest_paths.dense`,
180
`networkx.algorithms.shortest_paths.generic`,
165
`networkx.algorithms.shortest_paths.unweighted`,
168
`networkx.algorithms.shortest_paths.weighted`,
171
`networkx.algorithms.simple_paths`, 183
`networkx.algorithms.swap`, 185
`networkx.algorithms.traversal.breadth_first_search`,
191
`networkx.algorithms.traversal.depth_first_search`,
186
`networkx.algorithms.traversal.edgedfs`,
193
`networkx.algorithms.tree.branchings`, 197
`networkx.algorithms.tree.recognition`,
194
`networkx.algorithms.triads`, 199
`networkx.algorithms.vitality`, 200

C

`networkx.classes.function`, 201
`networkx.convert`, 263
`networkx.convert_matrix`, 266

d

`networkx.drawing.layout`, 321
`networkx.drawing.nx_agraph`, 317
`networkx.drawing.nx_pydot`, 319
`networkx.drawing.nx_pylab`, 309

e

`networkx.exception`, 325

g

`networkx.generators.atlas`, 209
`networkx.generators.classic`, 209
`networkx.generators.community`, 245
`networkx.generators.degree_seq`, 227
`networkx.generators.directed`, 234
`networkx.generators.ego`, 241
`networkx.generators.expanders`, 214
`networkx.generators.geometric`, 237
`networkx.generators.intersection`, 243
`networkx.generators.line`, 240
`networkx.generators.nonisomorphic_trees`,
249
`networkx.generators.random_clustered`,
233
`networkx.generators.random_graphs`, 219
`networkx.generators.small`, 215
`networkx.generators.social`, 244
`networkx.generators.stochastic`, 242

l

`networkx.linalg.algebraicconnectivity`,
256
`networkx.linalg.attrmatrix`, 258
`networkx.linalg.graphmatrix`, 251
`networkx.linalg.laplacianmatrix`, 252
`networkx.linalg.spectrum`, 255

r

`networkx.readwrite.adjlist`, 275
`networkx.readwrite.edgelist`, 282
`networkx.readwrite.gexf`, 288
`networkx.readwrite.gml`, 290
`networkx.readwrite.gpickle`, 294
`networkx.readwrite.graph6`, 300
`networkx.readwrite.graphml`, 295
`networkx.readwrite.json_graph`, 298
`networkx.readwrite.leda`, 298
`networkx.readwrite.multiline_adjlist`,
278
`networkx.readwrite.nx_shp`, 307
`networkx.readwrite.nx_yaml`, 299
`networkx.readwrite.pajek`, 306
`networkx.readwrite.sparse6`, 303

U

`networkx.utils`, [327](#)
`networkx.utils.contextmanagers`, [333](#)
`networkx.utils.decorators`, [330](#)
`networkx.utils.misc`, [327](#)
`networkx.utils.random_sequence`, [328](#)
`networkx.utils.rcm`, [331](#)
`networkx.utils.union_find`, [328](#)

Symbols

`__init__()` (Edmonds method), 199

A

`adamic_adar_index()` (in module `networkx.algorithms.link_prediction`), 143

`adjacency_matrix()` (in module `networkx.linalg.graphmatrix`), 251

`adjacency_spectrum()` (in module `networkx.linalg.spectrum`), 255

`algebraic_connectivity()` (in module `networkx.linalg.algebraicconnectivity`), 256

`all_neighbors()` (in module `networkx.classes.function`), 203

`all_node_cuts()` (in module `networkx.algorithms.connectivity.kcutsets`), 92

`all_pairs_dijkstra_path()` (in module `networkx.algorithms.shortest_paths.weighted`), 174

`all_pairs_dijkstra_path_length()` (in module `networkx.algorithms.shortest_paths.weighted`), 175

`all_pairs_node_connectivity()` (in module `networkx.algorithms.approximation.connectivity`), 25

`all_pairs_node_connectivity()` (in module `networkx.algorithms.connectivity.connectivity`), 94

`all_pairs_shortest_path()` (in module `networkx.algorithms.shortest_paths.unweighted`), 170

`all_pairs_shortest_path_length()` (in module `networkx.algorithms.shortest_paths.unweighted`), 170

`all_shortest_paths()` (in module `networkx.algorithms.shortest_paths.generic`), 166

`all_simple_paths()` (in module `networkx.algorithms.simple_paths`), 183

`alternating_havel_hakimi_graph()` (in module `networkx.algorithms.bipartite.generators`), 58

`ancestors()` (in module `networkx.algorithms.dag`), 115

`antichains()` (in module `networkx.algorithms.dag`), 118

`articulation_points()` (in module `networkx.algorithms.components.biconnected`), 89

`astar_path()` (in module `networkx.algorithms.shortest_paths.astar`), 182

`astar_path_length()` (in module `networkx.algorithms.shortest_paths.astar`), 182

`attr_matrix()` (in module `networkx.linalg.attrmatrix`), 259

`attr_sparse_matrix()` (in module `networkx.linalg.attrmatrix`), 260

`attracting_component_subgraphs()` (in module `networkx.algorithms.components.attracting`), 85

`attracting_components()` (in module `networkx.algorithms.components.attracting`), 84

`authority_matrix()` (in module `networkx.algorithms.link_analysis.hits_alg`), 142

`average_clustering()` (in module `networkx.algorithms.approximation.clustering_coefficient`), 30

`average_clustering()` (in module `networkx.algorithms.bipartite.cluster`), 50

`average_clustering()` (in module `networkx.algorithms.cluster`), 72

`average_node_connectivity()` (in module `networkx.algorithms.connectivity.connectivity`), 93

`average_shortest_path_length()` (in module `networkx.algorithms.shortest_paths.generic`), 168

B

`balanced_tree()` (in module `networkx.generators.classic`), 210

`barabasi_albert_graph()` (in module `networkx.generators.random_graphs`), 225

`barbell_graph()` (in module `networkx.generators.classic`), 210

- p>bellman_ford() (in module net-workx.algorithms.shortest_paths.weighted), 178
- betweenness_centrality() (in module net-workx.algorithms.bipartite.centrality), 55
- bfs_edges() (in module net-workx.algorithms.traversal.breadth_first_search), 191
- bfs_predecessors() (in module net-workx.algorithms.traversal.breadth_first_search), 192
- bfs_successors() (in module net-workx.algorithms.traversal.breadth_first_search), 192
- bfs_tree() (in module net-workx.algorithms.traversal.breadth_first_search), 191
- biadjacency_matrix() (in module net-workx.algorithms.bipartite.matrix), 41
- biconnected_component_edges() (in module net-workx.algorithms.components.biconnected), 87
- biconnected_component_subgraphs() (in module net-workx.algorithms.components.biconnected), 88
- biconnected_components() (in module net-workx.algorithms.components.biconnected), 86
- bidirectional_dijkstra() (in module net-workx.algorithms.shortest_paths.weighted), 176
- binomial_graph() (in module net-workx.generators.random_graphs), 222
- blockmodel() (in module networkx.algorithms.block), 61
- branching_weight() (in module net-workx.algorithms.tree.branchings), 197
- build_auxiliary_edge_connectivity() (in module net-workx.algorithms.connectivity.utils), 108
- build_auxiliary_node_connectivity() (in module net-workx.algorithms.connectivity.utils), 109
- bull_graph() (in module networkx.generators.small), 217
- C**
- cartesian_product() (in module net-workx.algorithms.operators.product), 160
- caveman_graph() (in module net-workx.generators.community), 245
- center() (in module net-workx.algorithms.distance_measures), 119
- chordal_cycle_graph() (in module net-workx.generators.expanders), 215
- chordal_graph_cliques() (in module net-workx.algorithms.chordal.chordal_alg), 65
- chordal_graph_treewidth() (in module net-workx.algorithms.chordal.chordal_alg), 66
- chvatal_graph() (in module networkx.generators.small), 217
- circular_ladder_graph() (in module net-workx.generators.classic), 212
- circular_layout() (in module networkx.drawing.layout), 322
- clique_removal() (in module net-workx.algorithms.approximation.clique), 29
- cliques_containing_node() (in module net-workx.algorithms.clique), 70
- closeness_centrality() (in module net-workx.algorithms.bipartite.centrality), 54
- closeness_vitality() (in module net-workx.algorithms.vitality), 200
- clustering() (in module net-workx.algorithms.bipartite.cluster), 48
- clustering() (in module networkx.algorithms.cluster), 71
- cn_soundarajan_hopcroft() (in module net-workx.algorithms.link_prediction), 145
- collaboration_weighted_projected_graph() (in module networkx.algorithms.bipartite.projection), 44
- color() (in module networkx.algorithms.bipartite.basic), 37
- common_neighbors() (in module net-workx.classes.function), 204
- complement() (in module net-workx.algorithms.operators.unary), 155
- complete_bipartite_graph() (in module net-workx.algorithms.bipartite.generators), 56
- complete_graph() (in module net-workx.generators.classic), 211
- complete_multipartite_graph() (in module net-workx.generators.classic), 211
- compose() (in module net-workx.algorithms.operators.binary), 156
- compose_all() (in module net-workx.algorithms.operators.all), 159
- condensation() (in module net-workx.algorithms.components.strongly_connected), 81
- configuration_model() (in module net-workx.algorithms.bipartite.generators), 57
- configuration_model() (in module net-workx.generators.degree_seq), 228
- connected_caveman_graph() (in module net-workx.generators.community), 246
- connected_component_subgraphs() (in module net-workx.algorithms.components.connected), 76
- connected_components() (in module net-workx.algorithms.components.connected),

- 76
- `connected_double_edge_swap()` (in module `networkx.algorithms.swap`), 186
- `connected_watts_strogatz_graph()` (in module `networkx.generators.random_graphs`), 224
- `contracted_edge()` (in module `networkx.algorithms.minors`), 149
- `contracted_nodes()` (in module `networkx.algorithms.minors`), 150
- `core_number()` (in module `networkx.algorithms.core`), 109
- `create_degree_sequence()` (in module `networkx.utils.random_sequence`), 328
- `create_empty_copy()` (in module `networkx.classes.function`), 202
- `cubical_graph()` (in module `networkx.generators.small`), 217
- `cumulative_distribution()` (in module `networkx.utils.random_sequence`), 329
- `cuthill_mckee_ordering()` (in module `networkx.utils.rcm`), 331
- `cycle_basis()` (in module `networkx.algorithms.cycles`), 112
- `cycle_graph()` (in module `networkx.generators.classic`), 212
- ## D
- `dag_longest_path()` (in module `networkx.algorithms.dag`), 118
- `dag_longest_path_length()` (in module `networkx.algorithms.dag`), 119
- `davis_southern_women_graph()` (in module `networkx.generators.social`), 244
- `default_opener()` (in module `networkx.utils.misc`), 328
- `degree()` (in module `networkx.classes.function`), 201
- `degree_centrality()` (in module `networkx.algorithms.bipartite.centrality`), 54
- `degree_histogram()` (in module `networkx.classes.function`), 201
- `degree_sequence_tree()` (in module `networkx.generators.degree_seq`), 232
- `degrees()` (in module `networkx.algorithms.bipartite.basic`), 38
- `dense_gnm_random_graph()` (in module `networkx.generators.random_graphs`), 221
- `density()` (in module `networkx.algorithms.bipartite.basic`), 38
- `density()` (in module `networkx.classes.function`), 201
- `desargues_graph()` (in module `networkx.generators.small`), 217
- `descendants()` (in module `networkx.algorithms.dag`), 115
- `dfs_edges()` (in module `networkx.algorithms.traversal.depth_first_search`), 187
- `dfs_labeled_edges()` (in module `networkx.algorithms.traversal.depth_first_search`), 190
- `dfs_postorder_nodes()` (in module `networkx.algorithms.traversal.depth_first_search`), 189
- `dfs_predecessors()` (in module `networkx.algorithms.traversal.depth_first_search`), 188
- `dfs_preorder_nodes()` (in module `networkx.algorithms.traversal.depth_first_search`), 189
- `dfs_successors()` (in module `networkx.algorithms.traversal.depth_first_search`), 188
- `dfs_tree()` (in module `networkx.algorithms.traversal.depth_first_search`), 187
- `diameter()` (in module `networkx.algorithms.distance_measures`), 119
- `diamond_graph()` (in module `networkx.generators.small`), 217
- `dictionary`, 343
- `difference()` (in module `networkx.algorithms.operators.binary`), 158
- `DiGraph()` (in module `networkx`), 13
- `dijkstra_path()` (in module `networkx.algorithms.shortest_paths.weighted`), 172
- `dijkstra_path_length()` (in module `networkx.algorithms.shortest_paths.weighted`), 172
- `dijkstra_predecessor_and_distance()` (in module `networkx.algorithms.shortest_paths.weighted`), 177
- `directed_configuration_model()` (in module `networkx.generators.degree_seq`), 229
- `directed_havel_hakimi_graph()` (in module `networkx.generators.degree_seq`), 232
- `directed_laplacian_matrix()` (in module `networkx.linalg.laplacianmatrix`), 254
- `discrete_sequence()` (in module `networkx.utils.random_sequence`), 329
- `disjoint_union()` (in module `networkx.algorithms.operators.binary`), 157
- `disjoint_union_all()` (in module `networkx.algorithms.operators.all`), 160
- `dodecahedral_graph()` (in module `networkx.generators.small`), 217
- `dominance_frontiers()` (in module `networkx.algorithms.dominance`), 123
- `dominating_set()` (in module `networkx.algorithms.dominating`), 124

dorogovtsev_goltsev_mendes_graph() (in module networkx.generators.classic), 212

double_edge_swap() (in module networkx.algorithms.swap), 185

draw() (in module networkx.drawing.nx_pylab), 309

draw_circular() (in module networkx.drawing.nx_pylab), 315

draw_graphviz() (in module networkx.drawing.nx_pylab), 316

draw_networkx() (in module networkx.drawing.nx_pylab), 310

draw_networkx_edge_labels() (in module networkx.drawing.nx_pylab), 315

draw_networkx_edges() (in module networkx.drawing.nx_pylab), 313

draw_networkx_labels() (in module networkx.drawing.nx_pylab), 314

draw_networkx_nodes() (in module networkx.drawing.nx_pylab), 312

draw_random() (in module networkx.drawing.nx_pylab), 316

draw_shell() (in module networkx.drawing.nx_pylab), 316

draw_spectral() (in module networkx.drawing.nx_pylab), 316

draw_spring() (in module networkx.drawing.nx_pylab), 316

duplication_divergence_graph() (in module networkx.generators.random_graphs), 226

E

ebunch, 343

eccentricity() (in module networkx.algorithms.distance_measures), 120

edge, 343

edge attribute, 343

edge_boundary() (in module networkx.algorithms.boundary), 62

edge_connectivity() (in module networkx.algorithms.connectivity.connectivity), 95

edge_dfs() (in module networkx.algorithms.traversal.edgedfs), 193

edges() (in module networkx.classes.function), 204

edges_iter() (in module networkx.classes.function), 204

Edmonds (class in networkx.algorithms.tree.branchings), 199

ego_graph() (in module networkx.generators.ego), 242

empty_graph() (in module networkx.generators.classic), 212

enumerate_all_cliques() (in module networkx.algorithms.clique), 68

eppstein_matching() (in module networkx.algorithms.bipartite.matching), 39

erdos_renyi_graph() (in module networkx.generators.random_graphs), 222

eulerian_circuit() (in module networkx.algorithms.euler), 125

expected_degree_graph() (in module networkx.generators.degree_seq), 230

F

fast_gnp_random_graph() (in module networkx.generators.random_graphs), 220

fiedler_vector() (in module networkx.linalg.algebraicconnectivity), 257

find_cliques() (in module networkx.algorithms.clique), 68

find_cycle() (in module networkx.algorithms.cycles), 114

find_induced_nodes() (in module networkx.algorithms.chordal.chordal_alg), 66

flatten() (in module networkx.utils.misc), 327

florentine_families_graph() (in module networkx.generators.social), 245

flow_hierarchy() (in module networkx.algorithms.hierarchy), 130

floyd_warshall() (in module networkx.algorithms.shortest_paths.dense), 180

floyd_warshall_numpy() (in module networkx.algorithms.shortest_paths.dense), 181

floyd_warshall_predecessor_and_distance() (in module networkx.algorithms.shortest_paths.dense), 180

freeze() (in module networkx.classes.function), 207

from_agraph() (in module networkx.drawing.nx_agraph), 317

from_biadjacency_matrix() (in module networkx.algorithms.bipartite.matrix), 42

from_dict_of_dicts() (in module networkx.convert), 264

from_dict_of_lists() (in module networkx.convert), 265

from_edgelist() (in module networkx.convert), 266

from_numpy_matrix() (in module networkx.convert_matrix), 269

from_pandas_dataframe() (in module networkx.convert_matrix), 274

from_pydot() (in module networkx.drawing.nx_pydot), 320

from_scipy_sparse_matrix() (in module networkx.convert_matrix), 271

frucht_graph() (in module networkx.generators.small), 217

G

gaussian_random_partition_graph() (in module networkx.generators.community), 248

- [general_random_intersection_graph\(\)](#) (in module `networkx.generators.intersection`), 243
[generate_adjlist\(\)](#) (in module `networkx.readwrite.adjlist`), 278
[generate_edgelist\(\)](#) (in module `networkx.readwrite.edgelist`), 286
[generate_gml\(\)](#) (in module `networkx.readwrite.gml`), 292
[generate_graph6\(\)](#) (in module `networkx.readwrite.graph6`), 302
[generate_multiline_adjlist\(\)](#) (in module `networkx.readwrite.multiline_adjlist`), 281
[generate_sparse6\(\)](#) (in module `networkx.readwrite.sparse6`), 304
[generate_unique_node\(\)](#) (in module `networkx.utils.misc`), 328
[generic_weighted_projected_graph\(\)](#) (in module `networkx.algorithms.bipartite.projection`), 46
[geographical_threshold_graph\(\)](#) (in module `networkx.generators.geometric`), 238
[get_edge_attributes\(\)](#) (in module `networkx.classes.function`), 206
[get_node_attributes\(\)](#) (in module `networkx.classes.function`), 205
[global_parameters\(\)](#) (in module `networkx.algorithms.distance_regular`), 122
[gn_graph\(\)](#) (in module `networkx.generators.directed`), 235
[gnc_graph\(\)](#) (in module `networkx.generators.directed`), 236
[gnm_random_graph\(\)](#) (in module `networkx.generators.random_graphs`), 221
[gnmk_random_graph\(\)](#) (in module `networkx.algorithms.bipartite.generators`), 60
[gnp_random_graph\(\)](#) (in module `networkx.generators.random_graphs`), 220
[gnr_graph\(\)](#) (in module `networkx.generators.directed`), 235
[google_matrix\(\)](#) (in module `networkx.algorithms.link_analysis.pagerank_alg`), 139
[Graph\(\)](#) (in module `networkx`), 9
[graph_atlas_g\(\)](#) (in module `networkx.generators.atlas`), 209
[graph_clique_number\(\)](#) (in module `networkx.algorithms.clique`), 69
[graph_number_of_cliques\(\)](#) (in module `networkx.algorithms.clique`), 70
[graphviz_layout\(\)](#) (in module `networkx.drawing.nx_agraph`), 318
[graphviz_layout\(\)](#) (in module `networkx.drawing.nx_pydot`), 321
[greedy_branching\(\)](#) (in module `networkx.algorithms.tree.branchings`), 197
[grid_2d_graph\(\)](#) (in module `networkx.generators.classic`), 213
[grid_graph\(\)](#) (in module `networkx.generators.classic`), 213
- ## H
- [has_path\(\)](#) (in module `networkx.algorithms.shortest_paths.generic`), 168
[hashable](#), 343
[havel_hakimi_graph\(\)](#) (in module `networkx.algorithms.bipartite.generators`), 57
[havel_hakimi_graph\(\)](#) (in module `networkx.generators.degree_seq`), 231
[heawood_graph\(\)](#) (in module `networkx.generators.small`), 218
[hits\(\)](#) (in module `networkx.algorithms.link_analysis.hits_alg`), 140
[hits_numpy\(\)](#) (in module `networkx.algorithms.link_analysis.hits_alg`), 140
[hits_scipy\(\)](#) (in module `networkx.algorithms.link_analysis.hits_alg`), 141
[hopcroft_karp_matching\(\)](#) (in module `networkx.algorithms.bipartite.matching`), 40
[house_graph\(\)](#) (in module `networkx.generators.small`), 218
[house_x_graph\(\)](#) (in module `networkx.generators.small`), 218
[hub_matrix\(\)](#) (in module `networkx.algorithms.link_analysis.hits_alg`), 142
[hypercube_graph\(\)](#) (in module `networkx.generators.classic`), 213
- ## I
- [icosahedral_graph\(\)](#) (in module `networkx.generators.small`), 218
[identified_nodes\(\)](#) (in module `networkx.algorithms.minors`), 151
[immediate_dominators\(\)](#) (in module `networkx.algorithms.dominance`), 123
[incidence_matrix\(\)](#) (in module `networkx.linalg.graphmatrix`), 252
[info\(\)](#) (in module `networkx.classes.function`), 202
[intersection\(\)](#) (in module `networkx.algorithms.operators.binary`), 157
[intersection_all\(\)](#) (in module `networkx.algorithms.operators.all`), 160
[intersection_array\(\)](#) (in module `networkx.algorithms.distance_regular`), 121
[is_aperiodic\(\)](#) (in module `networkx.algorithms.dag`), 117

- `is_arborescence()` (in module `workx.algorithms.tree.recognition`), 196
`is_attracting_component()` (in module `workx.algorithms.components.attracting`), 84
`is_biconnected()` (in module `workx.algorithms.components.biconnected`), 85
`is_bipartite()` (in module `workx.algorithms.bipartite.basic`), 36
`is_bipartite_node_set()` (in module `workx.algorithms.bipartite.basic`), 36
`is_branching()` (in module `workx.algorithms.tree.recognition`), 197
`is_chordal()` (in module `workx.algorithms.chordal.chordal_alg`), 65
`is_connected()` (in module `workx.algorithms.components.connected`), 75
`is_digraphical()` (in module `workx.algorithms.graphical`), 128
`is_directed()` (in module `networkx.classes.function`), 202
`is_directed_acyclic_graph()` (in module `workx.algorithms.dag`), 117
`is_distance_regular()` (in module `workx.algorithms.distance_regular`), 121
`is_dominating_set()` (in module `workx.algorithms.dominating`), 124
`is_eulerian()` (in module `networkx.algorithms.euler`), 125
`is_forest()` (in module `workx.algorithms.tree.recognition`), 196
`is_frozen()` (in module `networkx.classes.function`), 207
`is_graphical()` (in module `workx.algorithms.graphical`), 127
`is_isolate()` (in module `networkx.algorithms.isolate`), 132
`is_kl_connected()` (in module `workx.algorithms.hybrid`), 132
`is_list_of_ints()` (in module `networkx.utils.misc`), 327
`is_multigraphical()` (in module `workx.algorithms.graphical`), 128
`is_pseudographical()` (in module `workx.algorithms.graphical`), 128
`is_semiconnected()` (in module `workx.algorithms.components.semiconnected`), 90
`is_string_like()` (in module `networkx.utils.misc`), 327
`is_strongly_connected()` (in module `workx.algorithms.components.strongly_connected`), 78
`is_tree()` (in module `workx.algorithms.tree.recognition`), 195
`is_valid_degree_sequence_erdos_gallai()` (in module `networkx.algorithms.graphical`), 129
`is_valid_degree_sequence_havel_hakimi()` (in module `networkx.algorithms.graphical`), 129
`is_weakly_connected()` (in module `workx.algorithms.components.weakly_connected`), 82
`isolates()` (in module `networkx.algorithms.isolate`), 133
`iterable()` (in module `networkx.utils.misc`), 327
- ## J
- `jaccard_coefficient()` (in module `workx.algorithms.link_prediction`), 143
`johnson()` (in module `workx.algorithms.shortest_paths.weighted`), 179
- ## K
- `k_clique_communities()` (in module `workx.algorithms.community.kclique`), 74
`k_components()` (in module `workx.algorithms.approximation.kcomponents`), 28
`k_components()` (in module `workx.algorithms.connectivity.kcomponents`), 91
`k_core()` (in module `networkx.algorithms.core`), 110
`k_corona()` (in module `networkx.algorithms.core`), 112
`k_crust()` (in module `networkx.algorithms.core`), 111
`k_random_intersection_graph()` (in module `workx.generators.intersection`), 243
`k_shell()` (in module `networkx.algorithms.core`), 110
`karate_club_graph()` (in module `workx.generators.social`), 244
`kl_connected_subgraph()` (in module `workx.algorithms.hybrid`), 131
`kosaraju_strongly_connected_components()` (in module `workx.algorithms.components.strongly_connected`), 80
`krackhardt_kite_graph()` (in module `workx.generators.small`), 218
- ## L
- `ladder_graph()` (in module `networkx.generators.classic`), 213
`laplacian_matrix()` (in module `workx.linalg.laplacianmatrix`), 253
`laplacian_spectrum()` (in module `workx.linalg.spectrum`), 255
`latapy_clustering()` (in module `workx.algorithms.bipartite.cluster`), 51
`LCF_graph()` (in module `networkx.generators.small`), 216
`lexicographic_product()` (in module `workx.algorithms.operators.product`), 161
`line_graph()` (in module `networkx.generators.line`), 240

- literal_destringizer() (in module networkx.readwrite.gml), 293
- literal_stringizer() (in module networkx.readwrite.gml), 293
- local_edge_connectivity() (in module networkx.algorithms.connectivity.connectivity), 96
- local_node_connectivity() (in module networkx.algorithms.approximation.connectivity), 26
- local_node_connectivity() (in module networkx.algorithms.connectivity.connectivity), 98
- lollipop_graph() (in module networkx.generators.classic), 213
- ## M
- make_clique_bipartite() (in module networkx.algorithms.clique), 69
- make_max_clique_graph() (in module networkx.algorithms.clique), 69
- make_small_graph() (in module networkx.generators.small), 216
- make_str() (in module networkx.utils.misc), 328
- margulis_gabber_galil_graph() (in module networkx.generators.expanders), 214
- max_clique() (in module networkx.algorithms.approximation.clique), 29
- max_weight_matching() (in module networkx.algorithms.matching), 148
- maximal_independent_set() (in module networkx.algorithms.mis), 153
- maximal_matching() (in module networkx.algorithms.matching), 148
- maximum_branching() (in module networkx.algorithms.tree.branchings), 198
- maximum_independent_set() (in module networkx.algorithms.approximation.independent_set), 32
- maximum_spanning_arborescence() (in module networkx.algorithms.tree.branchings), 198
- min_edge_dominating_set() (in module networkx.algorithms.approximation.dominating_set), 31
- min_maximal_matching() (in module networkx.algorithms.approximation.matching), 32
- min_weighted_dominating_set() (in module networkx.algorithms.approximation.dominating_set), 31
- min_weighted_vertex_cover() (in module networkx.algorithms.approximation.vertex_cover), 33
- minimum_branching() (in module networkx.algorithms.tree.branchings), 198
- minimum_edge_cut() (in module networkx.algorithms.connectivity.cuts), 101
- minimum_node_cut() (in module networkx.algorithms.connectivity.cuts), 103
- minimum_spanning_arborescence() (in module networkx.algorithms.tree.branchings), 199
- minimum_spanning_edges() (in module networkx.algorithms.mst), 154
- minimum_spanning_tree() (in module networkx.algorithms.mst), 154
- minimum_st_edge_cut() (in module networkx.algorithms.connectivity.cuts), 104
- minimum_st_node_cut() (in module networkx.algorithms.connectivity.cuts), 105
- moebius_kantor_graph() (in module networkx.generators.small), 218
- MultiDiGraph() (in module networkx), 20
- MultiGraph() (in module networkx), 17
- ## N
- navigable_small_world_graph() (in module networkx.generators.geometric), 239
- nbunch, 343
- negative_edge_cycle() (in module networkx.algorithms.shortest_paths.weighted), 178
- networkx.algorithms.approximation (module), 25
- networkx.algorithms.approximation.clique (module), 29
- networkx.algorithms.approximation.clustering_coefficient (module), 30
- networkx.algorithms.approximation.connectivity (module), 25
- networkx.algorithms.approximation.dominating_set (module), 30
- networkx.algorithms.approximation.independent_set (module), 31
- networkx.algorithms.approximation.kcomponents (module), 27
- networkx.algorithms.approximation.matching (module), 32
- networkx.algorithms.approximation.ramsey (module), 33
- networkx.algorithms.approximation.vertex_cover (module), 33
- networkx.algorithms.assortativity (module), 34
- networkx.algorithms.bipartite (module), 34
- networkx.algorithms.bipartite.basic (module), 35
- networkx.algorithms.bipartite.centralities (module), 53
- networkx.algorithms.bipartite.cluster (module), 48
- networkx.algorithms.bipartite.generators (module), 56
- networkx.algorithms.bipartite.matching (module), 39
- networkx.algorithms.bipartite.matrix (module), 41
- networkx.algorithms.bipartite.projection (module), 42

`networkx.algorithms.bipartite.redundancy` (module), 52
`networkx.algorithms.bipartite.spectral` (module), 47
`networkx.algorithms.block` (module), 61
`networkx.algorithms.boundary` (module), 61
`networkx.algorithms.centrality` (module), 63
`networkx.algorithms.chordal.chordal_alg` (module), 64
`networkx.algorithms.clique` (module), 67
`networkx.algorithms.cluster` (module), 70
`networkx.algorithms.coloring` (module), 74
`networkx.algorithms.community` (module), 74
`networkx.algorithms.community.kclique` (module), 74
`networkx.algorithms.components` (module), 75
`networkx.algorithms.components.attracting` (module), 84
`networkx.algorithms.components.biconnected` (module), 85
`networkx.algorithms.components.connected` (module), 75
`networkx.algorithms.components.semiconnected` (module), 90
`networkx.algorithms.components.strongly_connected` (module), 77
`networkx.algorithms.components.weakly_connected` (module), 81
`networkx.algorithms.connectivity` (module), 91
`networkx.algorithms.connectivity.connectivity` (module), 93
`networkx.algorithms.connectivity.cuts` (module), 101
`networkx.algorithms.connectivity.kcomponents` (module), 91
`networkx.algorithms.connectivity.kcutsets` (module), 92
`networkx.algorithms.connectivity.stoerwagner` (module), 107
`networkx.algorithms.connectivity.utils` (module), 108
`networkx.algorithms.core` (module), 109
`networkx.algorithms.cycles` (module), 112
`networkx.algorithms.dag` (module), 115
`networkx.algorithms.distance_measures` (module), 119
`networkx.algorithms.distance_regular` (module), 121
`networkx.algorithms.dominance` (module), 123
`networkx.algorithms.dominating` (module), 124
`networkx.algorithms.euler` (module), 125
`networkx.algorithms.flow` (module), 126
`networkx.algorithms.graphical` (module), 127
`networkx.algorithms.hierarchy` (module), 130
`networkx.algorithms.hybrid` (module), 131
`networkx.algorithms.isolate` (module), 132
`networkx.algorithms.isomorphism` (module), 133
`networkx.algorithms.isomorphism.isomorphvf2` (module), 133
`networkx.algorithms.link_analysis.hits_alg` (module), 139
`networkx.algorithms.link_analysis.pagerank_alg` (module), 135
`networkx.algorithms.link_prediction` (module), 142
`networkx.algorithms.matching` (module), 148
`networkx.algorithms.minors` (module), 149
`networkx.algorithms.mis` (module), 153
`networkx.algorithms.mst` (module), 153
`networkx.algorithms.operators.all` (module), 158
`networkx.algorithms.operators.binary` (module), 156
`networkx.algorithms.operators.product` (module), 160
`networkx.algorithms.operators.unary` (module), 155
`networkx.algorithms.richclub` (module), 164
`networkx.algorithms.shortest_paths.astar` (module), 181
`networkx.algorithms.shortest_paths.dense` (module), 180
`networkx.algorithms.shortest_paths.generic` (module), 165
`networkx.algorithms.shortest_paths.unweighted` (module), 168
`networkx.algorithms.shortest_paths.weighted` (module), 171
`networkx.algorithms.simple_paths` (module), 183
`networkx.algorithms.swap` (module), 185
`networkx.algorithms.traversal.breadth_first_search` (module), 191
`networkx.algorithms.traversal.depth_first_search` (module), 186
`networkx.algorithms.traversal.edgedfs` (module), 193
`networkx.algorithms.tree.branchings` (module), 197
`networkx.algorithms.tree.recognition` (module), 194
`networkx.algorithms.triads` (module), 199
`networkx.algorithms.vitality` (module), 200
`networkx.classes.function` (module), 201
`networkx.convert` (module), 263
`networkx.convert_matrix` (module), 266
`networkx.drawing.layout` (module), 321
`networkx.drawing.nx_agraph` (module), 317
`networkx.drawing.nx_pydot` (module), 319
`networkx.drawing.nx_pylab` (module), 309
`networkx.exception` (module), 325
`networkx.generators.atlas` (module), 209
`networkx.generators.classic` (module), 209
`networkx.generators.community` (module), 245
`networkx.generators.degree_seq` (module), 227
`networkx.generators.directed` (module), 234
`networkx.generators.ego` (module), 241
`networkx.generators.expanders` (module), 214
`networkx.generators.geometric` (module), 237
`networkx.generators.intersection` (module), 243
`networkx.generators.line` (module), 240
`networkx.generators.nonisomorphic_trees` (module), 249
`networkx.generators.random_clustered` (module), 233
`networkx.generators.random_graphs` (module), 219
`networkx.generators.small` (module), 215
`networkx.generators.social` (module), 244
`networkx.generators.stochastic` (module), 242
`networkx.linalg.algebraicconnectivity` (module), 256
`networkx.linalg.attrmatrix` (module), 258

- networkx.linalg.graphmatrix (module), 251
 - networkx.linalg.laplacianmatrix (module), 252
 - networkx.linalg.spectrum (module), 255
 - networkx.readwrite.adjlist (module), 275
 - networkx.readwrite.edgelist (module), 282
 - networkx.readwrite.gexf (module), 288
 - networkx.readwrite.gml (module), 290
 - networkx.readwrite.gpickle (module), 294
 - networkx.readwrite.graph6 (module), 300
 - networkx.readwrite.graphml (module), 295
 - networkx.readwrite.json_graph (module), 298
 - networkx.readwrite.leda (module), 298
 - networkx.readwrite.multiline_adjlist (module), 278
 - networkx.readwrite.nx_shp (module), 307
 - networkx.readwrite.nx_yaml (module), 299
 - networkx.readwrite.pajek (module), 306
 - networkx.readwrite.sparse6 (module), 303
 - networkx.utils (module), 327
 - networkx.utils.contextmanagers (module), 333
 - networkx.utils.decorators (module), 330
 - networkx.utils.misc (module), 327
 - networkx.utils.random_sequence (module), 328
 - networkx.utils.rcm (module), 331
 - networkx.utils.union_find (module), 328
 - NetworkXAlgorithmError (class in networkx), 325
 - NetworkXError (class in networkx), 325
 - NetworkXException (class in networkx), 325
 - NetworkXNoPath (class in networkx), 325
 - NetworkXPointlessConcept (class in networkx), 325
 - NetworkXUnbounded (class in networkx), 325
 - NetworkXUnfeasible (class in networkx), 325
 - newman_watts_strogatz_graph() (in module networkx.generators.random_graphs), 223
 - node, 343
 - node attribute, 343
 - node_boundary() (in module networkx.algorithms.boundary), 62
 - node_clique_number() (in module networkx.algorithms.clique), 70
 - node_connected_component() (in module networkx.algorithms.components.connected), 77
 - node_connectivity() (in module networkx.algorithms.approximation.connectivity), 27
 - node_connectivity() (in module networkx.algorithms.connectivity.connectivity), 100
 - node_redundancy() (in module networkx.algorithms.bipartite.redundancy), 52
 - nodes() (in module networkx.classes.function), 203
 - nodes_iter() (in module networkx.classes.function), 203
 - non_edges() (in module networkx.classes.function), 205
 - non_neighbors() (in module networkx.classes.function), 203
 - nonisomorphic_trees() (in module networkx.generators.nonisomorphic_trees), 249
 - normalized_laplacian_matrix() (in module networkx.linalg.laplacianmatrix), 253
 - null_graph() (in module networkx.generators.classic), 214
 - number_attracting_components() (in module networkx.algorithms.components.attracting), 84
 - number_connected_components() (in module networkx.algorithms.components.connected), 75
 - number_of_cliques() (in module networkx.algorithms.clique), 70
 - number_of_edges() (in module networkx.classes.function), 204
 - number_of_nodes() (in module networkx.classes.function), 203
 - number_of_nonisomorphic_trees() (in module networkx.generators.nonisomorphic_trees), 249
 - number_strongly_connected_components() (in module networkx.algorithms.components.strongly_connected), 78
 - number_weakly_connected_components() (in module networkx.algorithms.components.weakly_connected), 82
- ## O
- octahedral_graph() (in module networkx.generators.small), 218
 - open_file() (in module networkx.utils.decorators), 330
 - overlap_weighted_projected_graph() (in module networkx.algorithms.bipartite.projection), 45
- ## P
- pagerank() (in module networkx.algorithms.link_analysis.pagerank_alg), 136
 - pagerank_numpy() (in module networkx.algorithms.link_analysis.pagerank_alg), 137
 - pagerank_scipy() (in module networkx.algorithms.link_analysis.pagerank_alg), 138
 - pappus_graph() (in module networkx.generators.small), 218
 - pareto_sequence() (in module networkx.utils.random_sequence), 329

- [parse_adjlist\(\)](#) (in module `networkx.readwrite.adjlist`), 277
[parse_edgelist\(\)](#) (in module `networkx.readwrite.edgelist`), 287
[parse_gml\(\)](#) (in module `networkx.readwrite.gml`), 292
[parse_graph6\(\)](#) (in module `networkx.readwrite.graph6`), 301
[parse_leda\(\)](#) (in module `networkx.readwrite.leda`), 299
[parse_multiline_adjlist\(\)](#) (in module `networkx.readwrite.multiline_adjlist`), 281
[parse_pajek\(\)](#) (in module `networkx.readwrite.pajek`), 307
[parse_sparse6\(\)](#) (in module `networkx.readwrite.sparse6`), 303
[path_graph\(\)](#) (in module `networkx.generators.classic`), 214
[periphery\(\)](#) (in module `networkx.algorithms.distance_measures`), 120
[petersen_graph\(\)](#) (in module `networkx.generators.small`), 218
[planted_partition_graph\(\)](#) (in module `networkx.generators.community`), 247
[power\(\)](#) (in module `networkx.algorithms.operators.product`), 163
[powerlaw_cluster_graph\(\)](#) (in module `networkx.generators.random_graphs`), 225
[powerlaw_sequence\(\)](#) (in module `networkx.utils.random_sequence`), 329
[predecessor\(\)](#) (in module `networkx.algorithms.shortest_paths.unweighted`), 171
[preferential_attachment\(\)](#) (in module `networkx.algorithms.link_prediction`), 144
[preferential_attachment_graph\(\)](#) (in module `networkx.algorithms.bipartite.generators`), 59
[projected_graph\(\)](#) (in module `networkx.algorithms.bipartite.projection`), 42
[pydot_layout\(\)](#) (in module `networkx.drawing.nx_pydot`), 321
[pygraphviz_layout\(\)](#) (in module `networkx.drawing.nx_agraph`), 319
- ## Q
- [quotient_graph\(\)](#) (in module `networkx.algorithms.minors`), 151
- ## R
- [ra_index_soumarajan_hopcroft\(\)](#) (in module `networkx.algorithms.link_prediction`), 146
[radius\(\)](#) (in module `networkx.algorithms.distance_measures`), 120
[ramsey_R2\(\)](#) (in module `networkx.algorithms.approximation.ramsey`), 33
[random_clustered_graph\(\)](#) (in module `networkx.generators.random_clustered`), 233
[random_degree_sequence_graph\(\)](#) (in module `networkx.generators.degree_seq`), 232
[random_geometric_graph\(\)](#) (in module `networkx.generators.geometric`), 237
[random_graph\(\)](#) (in module `networkx.algorithms.bipartite.generators`), 59
[random_layout\(\)](#) (in module `networkx.drawing.layout`), 322
[random_lobster\(\)](#) (in module `networkx.generators.random_graphs`), 226
[random_partition_graph\(\)](#) (in module `networkx.generators.community`), 247
[random_powerlaw_tree\(\)](#) (in module `networkx.generators.random_graphs`), 227
[random_powerlaw_tree_sequence\(\)](#) (in module `networkx.generators.random_graphs`), 227
[random_regular_graph\(\)](#) (in module `networkx.generators.random_graphs`), 224
[random_shell_graph\(\)](#) (in module `networkx.generators.random_graphs`), 226
[random_weighted_sample\(\)](#) (in module `networkx.utils.random_sequence`), 330
[read_adjlist\(\)](#) (in module `networkx.readwrite.adjlist`), 275
[read_dot\(\)](#) (in module `networkx.drawing.nx_agraph`), 318
[read_dot\(\)](#) (in module `networkx.drawing.nx_pydot`), 320
[read_edgelist\(\)](#) (in module `networkx.readwrite.edgelist`), 283
[read_gexf\(\)](#) (in module `networkx.readwrite.gexf`), 288
[read_gml\(\)](#) (in module `networkx.readwrite.gml`), 290
[read_gpickle\(\)](#) (in module `networkx.readwrite.gpickle`), 294
[read_graph6\(\)](#) (in module `networkx.readwrite.graph6`), 301
[read_graphml\(\)](#) (in module `networkx.readwrite.graphml`), 297
[read_leda\(\)](#) (in module `networkx.readwrite.leda`), 298
[read_multiline_adjlist\(\)](#) (in module `networkx.readwrite.multiline_adjlist`), 279
[read_pajek\(\)](#) (in module `networkx.readwrite.pajek`), 306
[read_shp\(\)](#) (in module `networkx.readwrite.nx_shp`), 307
[read_sparse6\(\)](#) (in module `networkx.readwrite.sparse6`), 304
[read_weighted_edgelist\(\)](#) (in module `networkx.readwrite.edgelist`), 285
[read_yaml\(\)](#) (in module `networkx.readwrite.nx_yaml`), 299
[relabel_gexf_graph\(\)](#) (in module `networkx.readwrite.gexf`), 290
[relaxed_caveman_graph\(\)](#) (in module `networkx.generators.community`), 246
[resource_allocation_index\(\)](#) (in module `networkx.algorithms.link_prediction`), 142

- reverse() (in module `networkx.algorithms.operators.unary`), 155
- reverse_cuthill_mckee_ordering() (in module `networkx.utils.rcm`), 332
- reverse_havel_hakimi_graph() (in module `networkx.algorithms.bipartite.generators`), 58
- reversed() (in module `networkx.utils.contextmanagers`), 333
- rich_club_coefficient() (in module `networkx.algorithms.richclub`), 164
- robins_alexander_clustering() (in module `networkx.algorithms.bipartite.cluster`), 52
- ## S
- scale_free_graph() (in module `networkx.generators.directed`), 236
- sedgewick_maze_graph() (in module `networkx.generators.small`), 219
- set_edge_attributes() (in module `networkx.classes.function`), 206
- set_node_attributes() (in module `networkx.classes.function`), 205
- sets() (in module `networkx.algorithms.bipartite.basic`), 37
- shell_layout() (in module `networkx.drawing.layout`), 322
- shortest_path() (in module `networkx.algorithms.shortest_paths.generic`), 165
- shortest_path_length() (in module `networkx.algorithms.shortest_paths.generic`), 167
- shortest_simple_paths() (in module `networkx.algorithms.simple_paths`), 184
- simple_cycles() (in module `networkx.algorithms.cycles`), 113
- single_source_dijkstra() (in module `networkx.algorithms.shortest_paths.weighted`), 175
- single_source_dijkstra_path() (in module `networkx.algorithms.shortest_paths.weighted`), 173
- single_source_dijkstra_path_length() (in module `networkx.algorithms.shortest_paths.weighted`), 173
- single_source_shortest_path() (in module `networkx.algorithms.shortest_paths.unweighted`), 169
- single_source_shortest_path_length() (in module `networkx.algorithms.shortest_paths.unweighted`), 169
- spectral_bipartivity() (in module `networkx.algorithms.bipartite.spectral`), 48
- spectral_layout() (in module `networkx.drawing.layout`), 324
- spectral_ordering() (in module `networkx.linalg.algebraicconnectivity`), 258
- spring_layout() (in module `networkx.drawing.layout`), 323
- square_clustering() (in module `networkx.algorithms.cluster`), 73
- star_graph() (in module `networkx.generators.classic`), 214
- stochastic_graph() (in module `networkx.generators.stochastic`), 242
- stoer_wagner() (in module `networkx.algorithms.connectivity.stoerwagner`), 107
- strong_product() (in module `networkx.algorithms.operators.product`), 162
- strongly_connected_component_subgraphs() (in module `networkx.algorithms.components.strongly_connected`), 79
- strongly_connected_components() (in module `networkx.algorithms.components.strongly_connected`), 78
- strongly_connected_components_recursive() (in module `networkx.algorithms.components.strongly_connected`), 80
- symmetric_difference() (in module `networkx.algorithms.operators.binary`), 158
- ## T
- tensor_product() (in module `networkx.algorithms.operators.product`), 162
- tetrahedral_graph() (in module `networkx.generators.small`), 219
- to_agraph() (in module `networkx.drawing.nx_agraph`), 318
- to_dict_of_dicts() (in module `networkx.convert`), 264
- to_dict_of_lists() (in module `networkx.convert`), 265
- to_edgelist() (in module `networkx.convert`), 265
- to_networkx_graph() (in module `networkx.convert`), 263
- to_numpy_matrix() (in module `networkx.convert_matrix`), 266
- to_numpy_recarray() (in module `networkx.convert_matrix`), 268
- to_pandas_dataframe() (in module `networkx.convert_matrix`), 272
- to_pydot() (in module `networkx.drawing.nx_pydot`), 320
- to_scipy_sparse_matrix() (in module `networkx.convert_matrix`), 270
- to_vertex_cover() (in module `networkx.algorithms.bipartite.matching`), 40
- topological_sort() (in module `networkx.algorithms.dag`), 116
- topological_sort_recursive() (in module `networkx.algorithms.dag`), 116

[transitive_closure\(\)](#) (in module `networkx.algorithms.dag`), 118
[transitivity\(\)](#) (in module `networkx.algorithms.cluster`), 71
[triadic_census\(\)](#) (in module `networkx.algorithms.triads`), 199
[triangles\(\)](#) (in module `networkx.algorithms.cluster`), 70
[trivial_graph\(\)](#) (in module `networkx.generators.classic`), 214
[truncated_cube_graph\(\)](#) (in module `networkx.generators.small`), 219
[truncated_tetrahedron_graph\(\)](#) (in module `networkx.generators.small`), 219
[tutte_graph\(\)](#) (in module `networkx.generators.small`), 219

U

[uniform_random_intersection_graph\(\)](#) (in module `networkx.generators.intersection`), 243
[uniform_sequence\(\)](#) (in module `networkx.utils.random_sequence`), 329
[union\(\)](#) (in module `networkx.algorithms.operators.binary`), 156
[union\(\)](#) (`UnionFind` method), 328
[union_all\(\)](#) (in module `networkx.algorithms.operators.all`), 159

W

[watts_strogatz_graph\(\)](#) (in module `networkx.generators.random_graphs`), 223
[waxman_graph\(\)](#) (in module `networkx.generators.geometric`), 239
[weakly_connected_component_subgraphs\(\)](#) (in module `networkx.algorithms.components.weakly_connected`), 83
[weakly_connected_components\(\)](#) (in module `networkx.algorithms.components.weakly_connected`), 82
[weighted_choice\(\)](#) (in module `networkx.utils.random_sequence`), 330
[weighted_projected_graph\(\)](#) (in module `networkx.algorithms.bipartite.projection`), 43
[wheel_graph\(\)](#) (in module `networkx.generators.classic`), 214
[within_inter_cluster\(\)](#) (in module `networkx.algorithms.link_prediction`), 147
[write_adjlist\(\)](#) (in module `networkx.readwrite.adjlist`), 276
[write_dot\(\)](#) (in module `networkx.drawing.nx_agraph`), 318
[write_dot\(\)](#) (in module `networkx.drawing.nx_pydot`), 320
[write_edgelist\(\)](#) (in module `networkx.readwrite.edgelist`), 284
[write_gexf\(\)](#) (in module `networkx.readwrite.gexf`), 289
[write_gml\(\)](#) (in module `networkx.readwrite.gml`), 291
[write_gpickle\(\)](#) (in module `networkx.readwrite.gpickle`), 294
[write_graph6\(\)](#) (in module `networkx.readwrite.graph6`), 302
[write_graphml\(\)](#) (in module `networkx.readwrite.graphml`), 297
[write_multiline_adjlist\(\)](#) (in module `networkx.readwrite.multiline_adjlist`), 280
[write_pajek\(\)](#) (in module `networkx.readwrite.pajek`), 306
[write_shp\(\)](#) (in module `networkx.readwrite.nx_shp`), 308
[write_sparse6\(\)](#) (in module `networkx.readwrite.sparse6`), 305
[write_weighted_edgelist\(\)](#) (in module `networkx.readwrite.edgelist`), 285
[write_yaml\(\)](#) (in module `networkx.readwrite.nx_yaml`), 300

Z

[zipf_rv\(\)](#) (in module `networkx.utils.random_sequence`), 329
[zipf_sequence\(\)](#) (in module `networkx.utils.random_sequence`), 329